HF RADAR TECHNOLOGY TRANSFER PROJECT - ACQUISITION PHASE, MARCH 1982

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C-CORE

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The Centre for Cold Ocean Resources Engineering (C-CORE) was established at Memorial Univeristy of Newfoundland in St. John's in 1975. Its initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. Ongoing funding now comes from governments and industry.

The Centre's mandate is to undertake research that will assist the safe and orderly development of Canada's resources in cold and ice frequented oceans.

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ABSTRACT

An operational single station surface current mapping Coastal Ocean Dynamic Applications Radar (CODAR) has been acquired by the Centre for Cold Ocean Resources Engineering (C-CORE).

The system was assembled and tested in February. 1982 at Cappahayden, Newfoundland. Equipment specifications are provided together with a preliminary discussion of field data analysis.

Recommendations for improvement and a program to acquire a complete two station CODAR facility are outlined.

ACKNOWLEDGEMENTS

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Our thanks to Ken Klein, Ernie Reimer and Deborah Diemand whose efforts made the Arctic HF program a success.

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1.0 INTRODUCTION

Recently a new remote sensing system called Coastal Ocean Dynamics Applications Radar (CODAR) has been developed for measuring ocean surface currents through Doppler processing of the high frequency (HF) surface wave backscatter from the ocean surface.

CODAR utilizes the 6 metre ocean wavelength which is one-half the electrical wavelength of the transmitted signal as a resonant structure satisfying the Bragg (first order) equation for scattering (Crombie, 1955). For any given ocean wavelength, the phase velocity of the approaching and receding wave can be analytically determined. Since Doppler frequency shift is a measure of velocity, it therefore can be shown that the Doppler frequency of the first order sea echo response is a measure of the phase velocity of the 6 metre ocean wave. We also know the transmitted wavelength, therefore we can calculate the expected Doppler response of the first order backscatter and thus assume that any difference in the measured first-order Doppler response is a measure of the near-surface currents running radial to the radar antenna. Although CODAR was a National Oceanic and Atmospheric Administration (NOAA) development, the overall work on this technique to date has taken place in many international government and university laboratories (Barrick and Evans, 1976; Trizna et al, 1977; Shearman et al, 1979; SRI International, 1980).

C-CORE. through its commitment to the development of Canadian cold ocean resources, has recently initiated a program to acquire

expertise with the CODAR technology. Supported by the Department of Fisheries and Oceans, the Centre's intention is to develop this technology further to meet Canada's special needs for remote ocean monitoring of both ice and ocean environmental conditions.

1.1 Scope of Development

Initial efforts were focussed on the goal of acquiring a complete two-site operational CODAR (Butt and Jeans, 1981). However. it soon became clear that the Canadian offshore community was not ready to make the immediate financial commitment to support such new technology.

Meanwhile, C-CORE with its mandate to develop applied sea ice engineering together with Memorial University's Ocean Engineering Group initiated a concentrated research effort on the remote sensing of sea ice and icebergs at high frequencies (HF).

The dual potential application for sea ice and ocean variable remote sensing prompted C-CORE to purchase the necessary hardware for a complete one-site Doppler HF radar. The scope of this acquisition phase was focussed on assembling the hardware to form an operational HF Doppler radar system and on developing the computer software to extend the system's operation to perform as a complete one-site CODAR for radial current mapping.

1.2 Program Objectives

The results reported here reflect the work performed under the Hardware Acquisition Phase of this technology transfer program. Supported primarily by Supply and Services Canada under

contract #0SS81-00129, the program had the following principal objectives:

1. To assemble an operational single site CODAR station. The bulk of the radar equipment was to be supplied by C-CORE with the necessary computer equipment. to be supplied under government contract.

2. To acquire and implement the latest CODAR data acquisition and interpretation software on the Canadian Government's LSI 11/23 computing facility at C-CORE (see HF Radar Technology Transfer Project - Evaluation Phase report under DSS contract file #46SZ.FP802-0-2205).

3. To carry out sufficient field tests from a site in the St. John's region to demonstrate single site CODAR operational capability.

4. To organize and carry out an Arctic field program to evaluate an analytical model developed to predict HF radio propagation over sea ice. The analytical model is being developed by the Ocean Engineering Group at Memorial University of Newfoundland under the supervision of Dr. John Walsh in cooperation with C-CORE. (The results of this program will be reported separately. For preliminary results see Appendix).

5. To report system performance of the single site CODAR equipment.

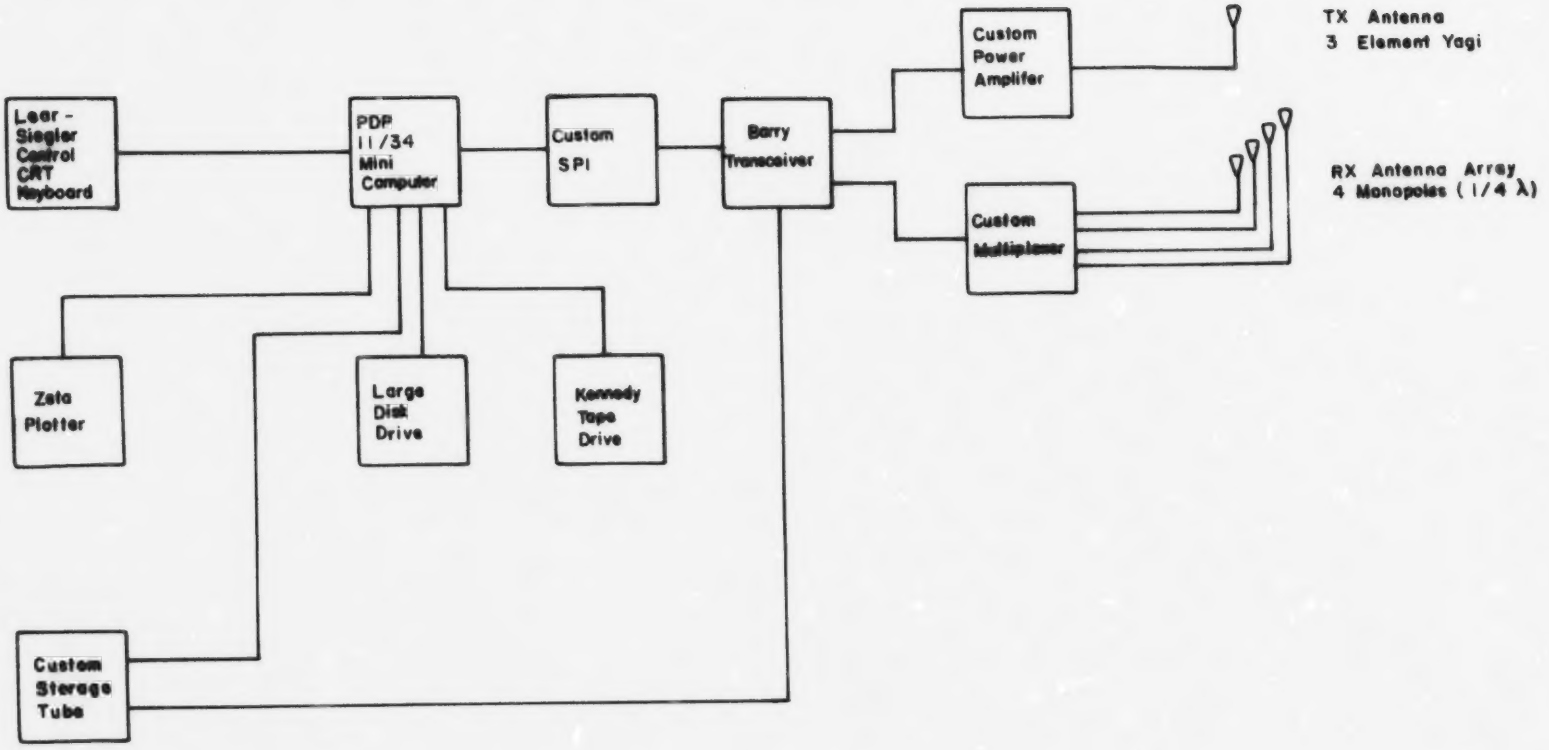


Figure 1: CODAR Original NOAA System Block Diagram (1 of 2 stations)

2.0 HARDWARE DESCRIPTION

CODAR components are primarily available through a company called CODAR Technology Inc. and the Wave Propagation Laboratory (WPL) of NOAA, both of Boulder, Colorado, U.S.A. However, special requirements here at C-CORE to support Canadian applications have required the development of some components locally.

All of the antenna equipment including the four signal multiplexer were constructed in Newfoundland by INSTRUMAR Limited.

A special transceiver control system has been designed in-house to permit radar operational control without a computer system. This will prove valuable for diagnostic purposes during field operation.

Significant changes in CODAR monitoring techniques have been initiated in-house with the use of latest plot options available for the computer.

The basic changes implemented through this program can be followed through Figures 1 to 3. Figure 1 outlines the original NOAA system used in most of their field tests up to 1980. Figure 2 outlines the actual system as developed under this project. Figure 3 outlines C-CORE's intentions for ongoing development.

A discussion of each of the individual components of the C-CORE CODAR is presented in the following sections under two major classifications, the (1) computer and (2) radar systems.

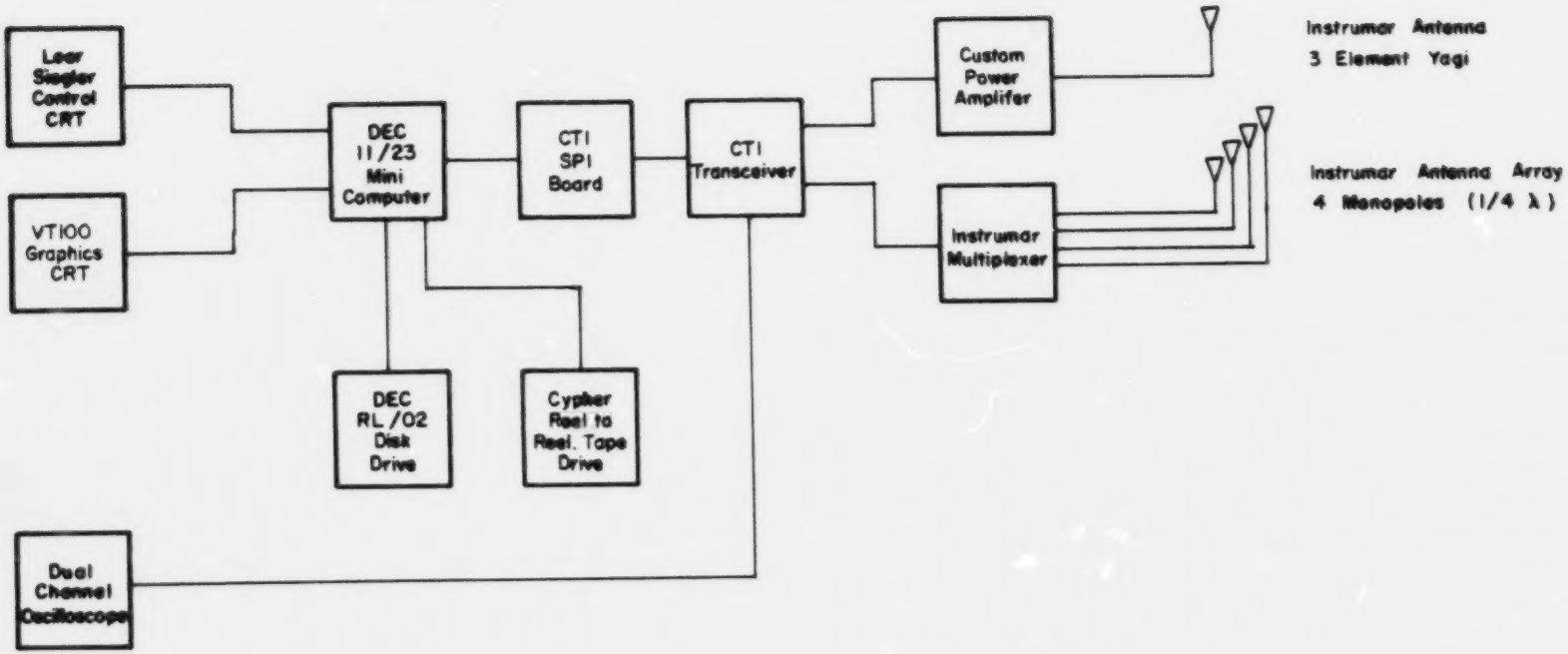


Figure 2: CODAR C-CORE Cappahayden Field Test System (Feb./82)

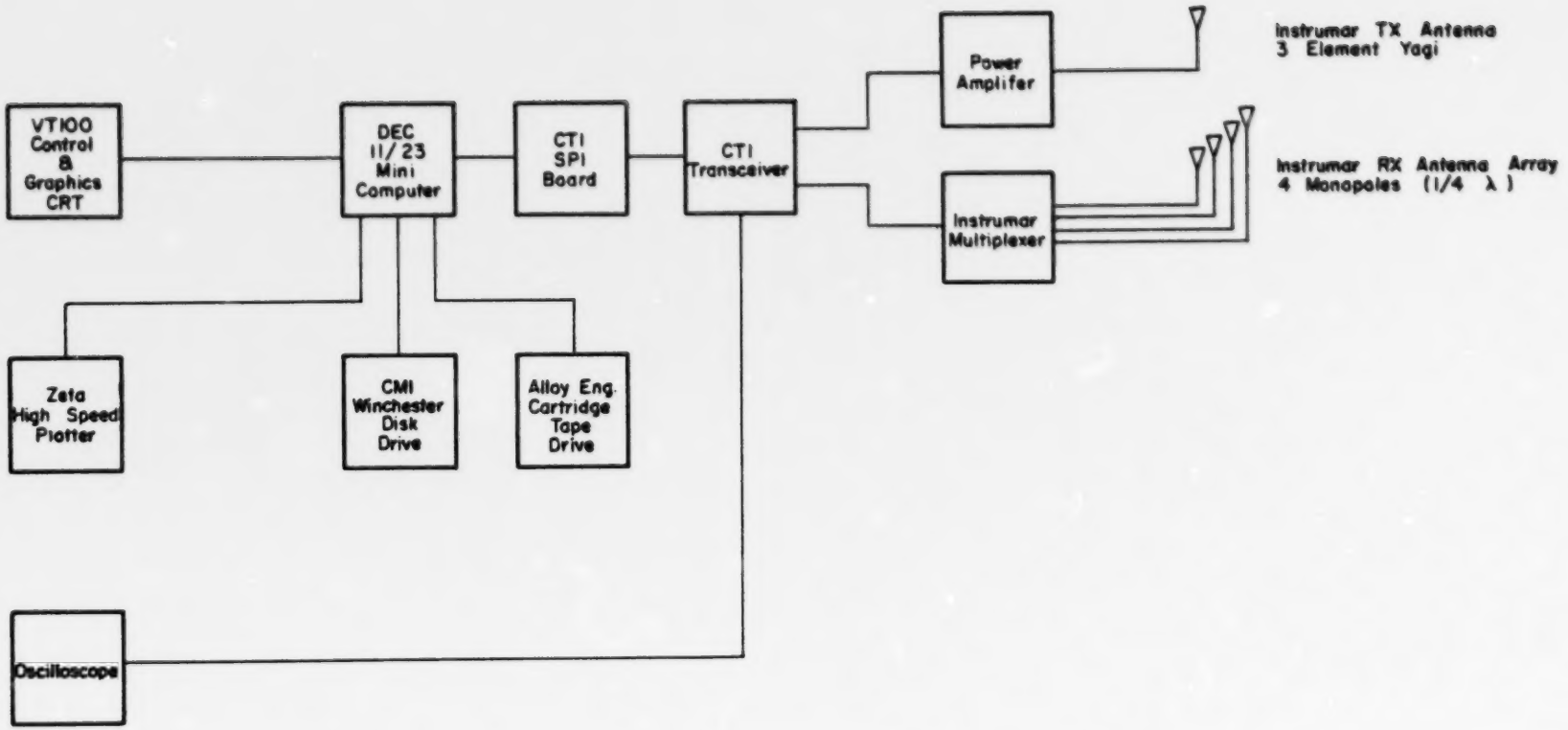


Figure 3: CODAR Proposed C-CORE System Block Diagram (1 of 2 stations)

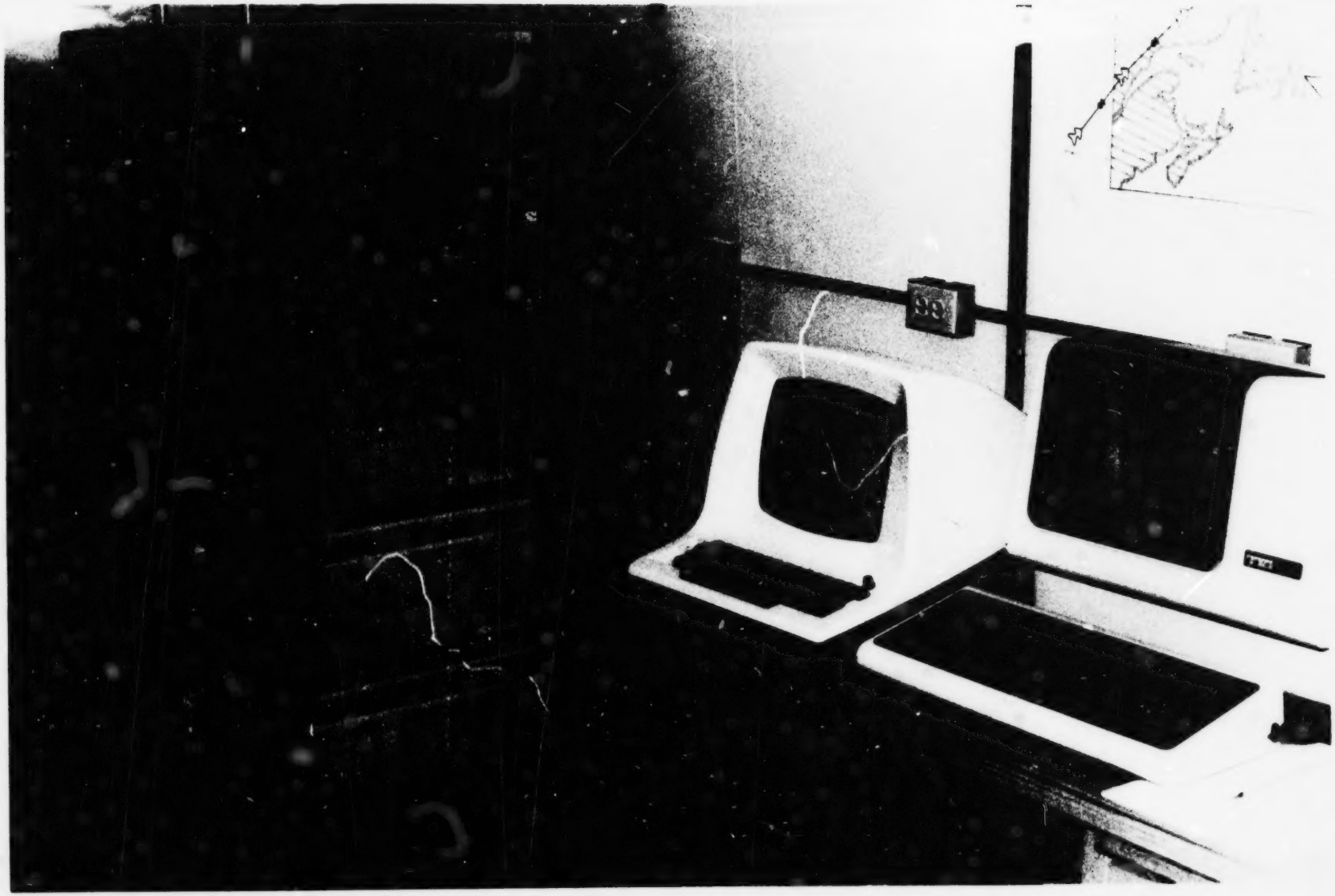


Figure 4: C-CORE CODAR Computer System - shown configured for laboratory operation are (L to R) sealed Winchester disk drive, computer mainframe, control terminal, display terminal. The computer mainframe contains (top to bottom) auto load reel-to-reel tape drive, blank space, first removable disk drive, second removable disk drive, LSI 11/23 computer.

2.1 Computer System

The following six sections describe the basic components comprising C-CORE's CODAR computer system. All of the components with the exception of the Signal Processing Interface (SPI) are standard to many computing facilities. Figure 4 shows the entire package configured for laboratory operation.

2.1.1 Computer Terminal

The entire CODAR system is directed from a keyboard CRT terminal. The C-CORE system uses the industry standard DIGITAL EQUIPMENT CORP. (DEC) VT100. Installed in this terminal is an "enhanced video option" board required by the present version of the CODAR acquisition software to enable special display functions. The terminal also contains a SELANAR graphics interface board discussed in the next section. Both boards are commercially available and are plugged directly into the VT100.

During this portion of the development phase an additional terminal manufactured by LEAR SIEGLER was used for control purposes while the above mentioned VT100 was used at Cappahayden only for graphics display and manual gain setup for the radar. The project's field test schedule did not allow the time required to implement the necessary software changes to multiplex the screen of the VT100 for both control and graphics display as is eventually planned.

The NOAA system presently uses a VT100 for control purposes only. They rely on their original custom screen display for operator interaction with the computer.

2.1.2 Graphics Display

The graphics display is used as an invaluable diagnostic tool during the acquisition phase of a CODAR run. The present C-CORE system uses a standard oscilloscope (TEK 465B) to display the I & Q video output of the receiver and a SELANAR computer graphics board (PL100) to display a short FFT power spectrum (32 sec / 128 point) and digitized I & Q time series. Graphics are displayed directly onto the VT100 screen with a dot resolution of 1225 horizontal and 240 vertical over an 20 cm X 12.5 cm area. The PL100 has its own separately addressable memory from that of the VT100 and can be updated by the computer using separate escape characters over the same serial line to the terminal. None of the VT100 capabilities are lost. The PL100 came with a plotting software package that has proven straight forward to use.

The NOAA graphics display consists of a custom built interface to a special storage tube. The storage tube is controlled by a microcomputer (INTEL 80 85) to either route the video I & Q directly from the receiver or accept plotting data from the computer to emulate a graphics terminal. This custom design, however, has not been available to C-CORE and a similar development was estimated to be impractical.

The graphics board/oscilloscope display system has proven to give suitable resolution, flexibility, reliability and ease of implementation. It eliminates one serial line from the computer and the in-house maintenance of custom built equipment. In retrospect it is cheaper to implement than the NOAA design. A low

cost X-Y CRT monitor will eventually replace the oscilliscope thus reducing the cost further.

2.1.3 Plotter

When data interpretation of a CODAR run is complete it is necessary to provide a hard copy output of the mapped vector current field. This is done by both C-CORE and NOAA using a NICOLETT ZETA CORP. 1553 digital incremental XY plotter. The CODAR software has been developed for this plotter and only one is required for a two station CODAR run.

2.1.4 Computer

The entire CODAR system is controlled by a DEC LSI 11/23 minicomputer using custom CODAR software. It represents the best cost to computing ratio at the present time. All of the existing software has been written for this machine.

The present system uses 128 k bytes of memory. However, it has been previously recommended that at least 192K bytes should be used (Butt and Jeans, 1981) to facilitate on-site program expansion. NOAA presently employs the full 256 k byte facility of the computer and analysis is currently underway to evaluate the benefits of using NOAA's new software within this configuration. The extra memory would reduce the required I/O operations and shorten the processing time.

2.1.5 Computer Mass Storage

The CODAR system produces a large volume of digital data for each run. A typical 18 minute run will result in 4.2 M bytes of information for each station of a two station CODAR site. To process this raw data after acquisition requires extensive computing time, much of which is data sorting and reshuffling between the 11/23 computer memory and the mass storage peripheral. At present the only practical storage for this random access of large quantities of data is a rigid magnetic disk system. Two RL02 disk drives from DEC were originally purchased for this purpose, as well as to provide the essential lab system. They are not, however, suited for field use because of their large size and weight and low reliability due to dust contamination of the magnetic medium. (The RL02 has removable disk cartridge drives and the disks are essentially open to the air).

Recently, however, a surge of development in the computer industry has focussed on smaller and lighter, fixed rigid disk drives, known in the industry as Winchesters. Rapid advance in this mass storage technology has encouraged C-CORE to purchase a disk drive from CMI (COMPUTER MEMORIES INC.) which can completely replace one RL02. The Winchester drive is shown in Figure 4 at the lower left of the photo and its size is then contrasted with an RL02 to its right. Its 3 disks are "5 1/4 inches" in diameter and are completely contained in a sealed dust free environment. One Winchester disk drive is required per site.

Late delivery of the Winchester drive precluded its use in the Cappahayden field tests. However the data interpretation of

these field tests will be run on this drive to simulate the required field data interpretation phase of CODAR. An RL02 disk drive was successfully used at the Cappahayden CODAR field trial. Although faster to implement, it was not essential for this purpose as the computer system can be booted from magnetic tape and operated within core memory on a more compact RSX-11S operating system.

In addition to a disk drive, a magnetic tape drive is required. It performs two main functions:

1. It provides an inexpensive permanent storage for the large quantity of both raw and processed data produced during a field program.
2. It can be used as a backup system for storage of all the software normally resident on disk.

NOAA has to date been predominantly using a KENNEDY model reel-to-reel tape drive.

Vast reductions in size and weight with increass in reliability and ease of operation can be achieved by using a "cartridge" type tape drive. It was originally planned to implement a cartridge tape drive during this phase of the development. Many of these relatively new technology tape drives are available but few are compatible with the CODAR software and hardware already established. A drive produced by Data Electronics, Inc. was acquired on trial, but was found not to emulate the reel-to-reel tape drive required by the DEC computer.

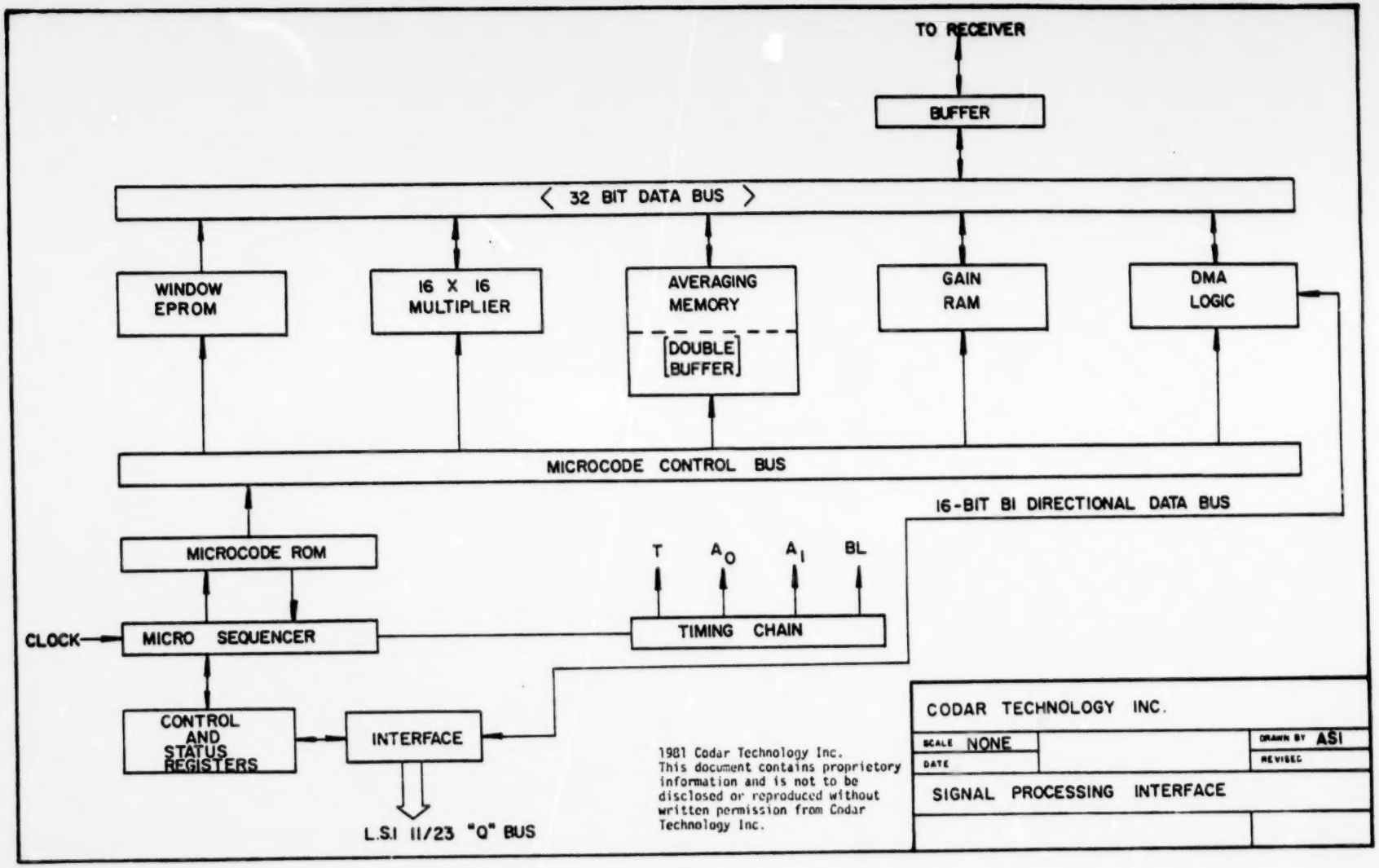


Figure 5: Signal Processing Interface Block Diagram

Inadequate buffering during track changes produced serious tape read errors. A QUANTEX cartridge tape drive using a serpentine (snake-like) track change format was subsequently acquired but was found to have problems in firmware that could not be rectified in time for our field work. Eventually it was decided to revert to a CIPHER 1/2 in. reel-to-reel auto load drive because of the ease of system integration. A standard 600' tape will hold slightly more than 36 minutes of present format CODAR data.

The program schedule did not allow enough time to evaluate another cartridge drive in time for the Cappahayden field tests. It is still planned to incorporate this technology in future development.

2.1.6 Signal Processing Interface Board

A specially designed printed circuit board called a Signal Processing Interface (SPI) is used to interface the computer to the radar system. It was designed by NOAA to relieve the overhead on the computer's Central Processing Unit (CPU).

This board enables the computer to accommodate the extremely high data rate coming from the radar output. A block diagram of the board function is shown in Figure 5. It is composed entirely of digital logic circuits and is installed inside the LSI 11/23 computer chassis.

The SPI board has many features:

1. It provides a double storage buffer of 1024 bytes each for the data from the radar receiver.

2. There are eight user selectable data "windows" located in 2048 bytes of memory located on the SPI board used for the signal processing.

3. It performs a pre-averaging of the data from the radar transceiver using the above mentioned buffers and one of the sample enhancing windows. (A Blackman - Harris window has been used the most). One buffer is filled and used for the averaging while the other is available to dump previously averaged data to the computer main memory using a Direct Memory Access (DMA) process. One hundred and twenty-eight samples of 12 bits are weighted by the window constants and averaged to give one 32 bit sample. This provides a signal to noise improvement of 10.5 dB. The least significant 16 bits of each sample are ignored once the averaging is completed.

4. A direct memory access capability is built into the Q bus interface on the SPI board. This provides the maximum possible data rate transfer to the computer.

5. A gain memory of 1536 bytes for the Sensitivity Time Control (STC) of the radar is located on the SPI board. This memory is loaded by the computer before each data run and contains the digitized gain constants for each range cell for each antenna.

6. The interface to the radar transceiver is over a 16 line digital bus. Four of these lines are control lines and 12 are a bidirectional data bus. Twelve bits of gain control constants are passed back from the SPI to the transceiver over these same lines at a later time.

7. There are extensive self diagnostics implemented in the design of the SPI which can detect a fault in the logic circuits before any erroneous data can be logged, a feature which proves invaluable to a real time operation.

8. The SPI also allows a powerful test of the interface to the transceiver and the Analog to Digital Converter (ADC) and Digital to Analog Converter (DAC) in the radar receiver. On a signal from the SPI the output of the DAC can be connected to the input of the ADC. Simulated radar data can then be passed through this connection from the SPI board.

9. The 2 MHz clock used on the SPI board is derived from the system master 10 MHz oscillator located in the transciever.

2.2 Radar System

The following seven sections describe the basic components comprising C-CORE's HF Doppler Radar. All components with the exception of the transponder and HF control box are required for an operational CODAR.

2.2.1 Transceiver

C-CORE's transceiver is shown in the centre of Figure 6. Although labled "receiver" it also provides the reference pulse to the transmitting amplifier, hence "transceiver". Built by ERBTEC ENGINEERING INC. and sold by C.T.I. it is a custom design specifically for CODAR operation and is implemented in a series of plug-in printed circuit boards for modularity of design and ease of maintenance. It is a direct evolution of NOAA's original

Figure 6: C-CORE HF Doppler Radar Equipment - Shown (top to bottom) are 4 signal multiplexer/filter; HF radar control; HF transceiver; HF power amplifier.

transceiver built by BARRY RESEARCH CORP. and identical units are now being used by NOAA. A block diagram of operation is presented in Figure 7.

The transceiver contains the basic reference oscillator of the entire radar. All of the required frequencies for the mixers are derived from this 10 MHz quartz crystal oscillator. It is oven stabilized and contained in a hermetically sealed module mounted on a card in the transceiver. A 2 MHz clock line is sent to the SPI board to synchronize both it and the CODAR software. On command from the computer, via the SPI board, a transmit pulse at the transmit frequency is generated in the transmitter and subsequently boosted by the power amplifier and radiated by the transmit antenna. The return signal from the receiver antenna array is first amplified by the multiplexer box and then routed to the input of the receiver strip in the transceiver. The signal is then coherently demodulated and heterodyned down to baseband using the reference frequencies derived directly from the transmitter portion.

Some of the features of the transceiver are;

1. Complete modular card cage design.

2. Complete computer control and monitoring.

3. Gain control via digital command from computer.

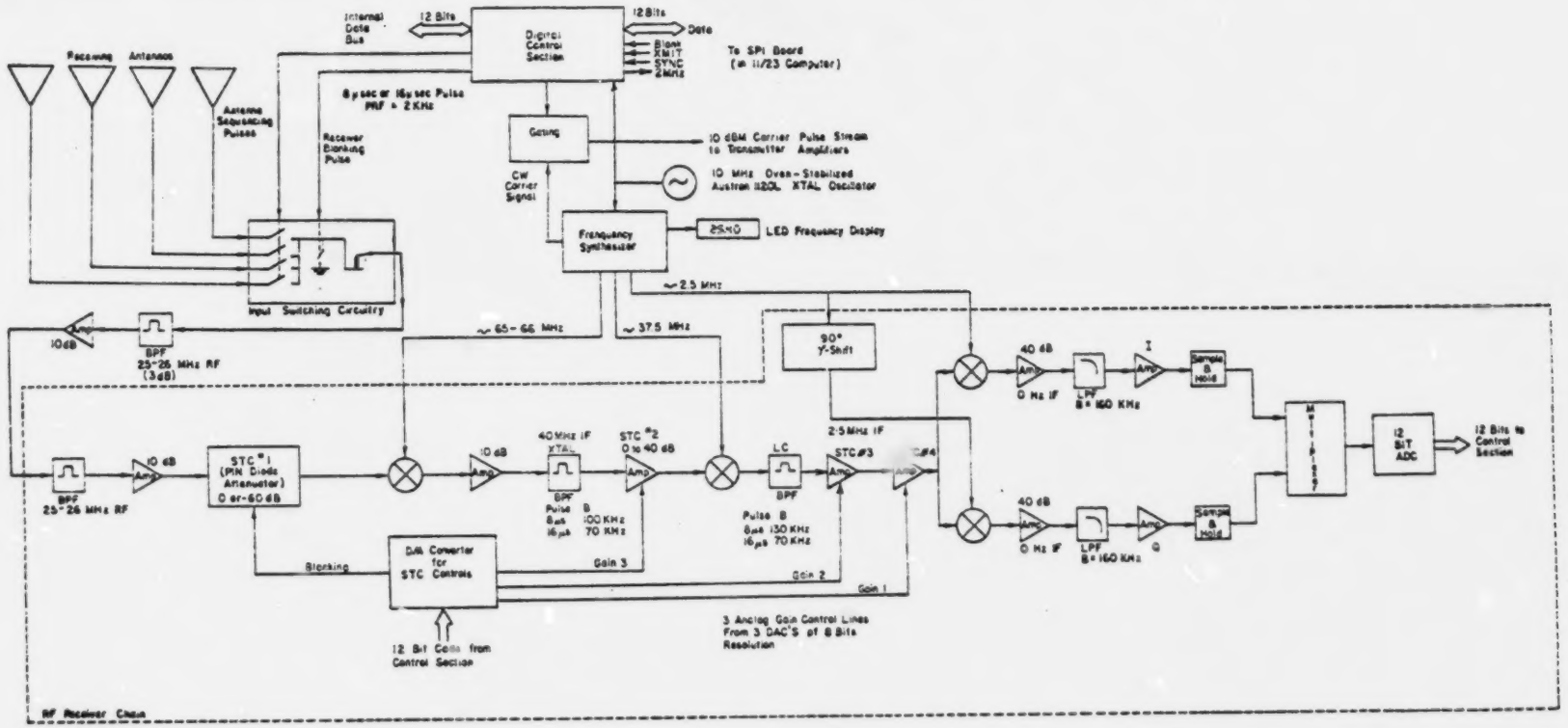


Figure 7: CODAR Transceiver Block Diagram

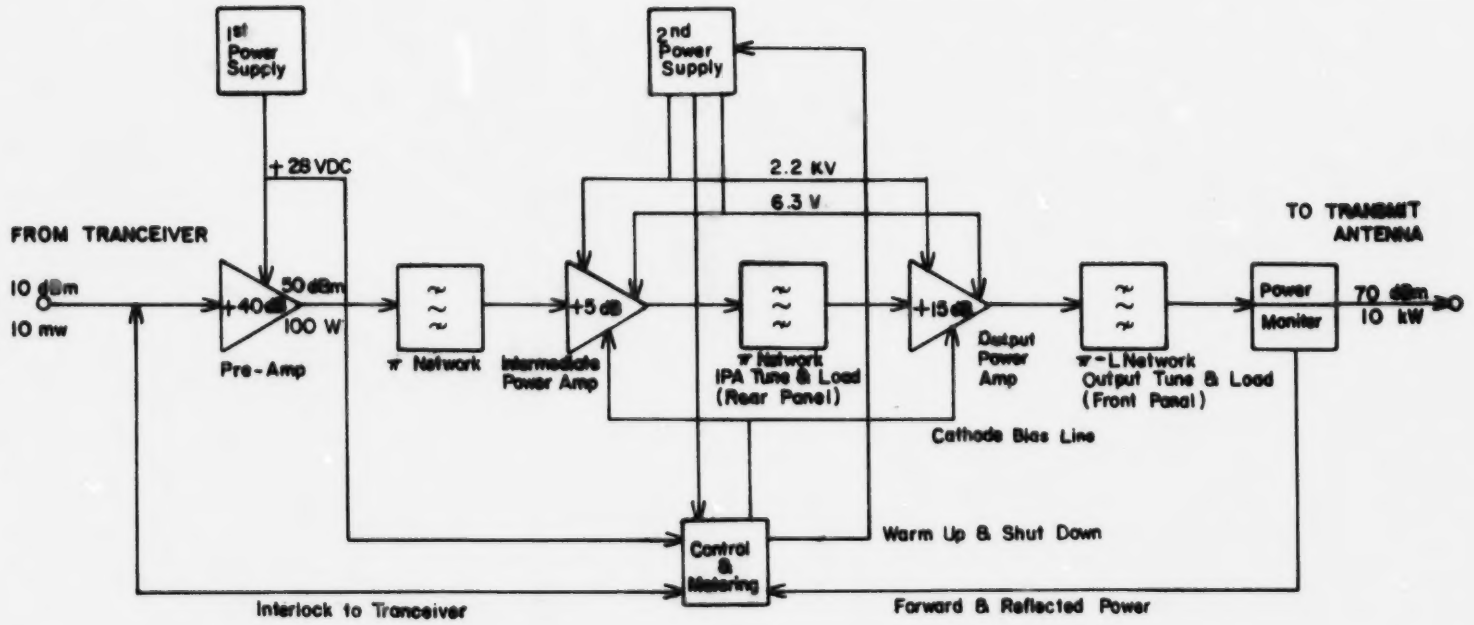
4. Transmit frequency chosen by digital command from computer.

5. A digital diagnostic mode can be implemented under computer control. Digital test words can be passed to the transceiver via the SPI board and read back again through the same SPI board. This tests the basic communications of the CODAR setup and critical digital circuitry in both the SPI board and the transceiver.

6. An analogue diagnostic mode can be implemented under computer control. On command from the computer the DAC's used for the gain control of the receiver can be connected to the ADC's used to sample the return radar signal. Digital test words from the computer can then check out these vital devices for any failures.

7. Status bits are continuously returned from the transceiver via the SPI board indicating the condition of various sub-modules in the transceiver. A status register on the SPI board can be continuously read by the computer to monitor hardware failure.

8. One of the above mentioned status bits indicates the condition of the transmit power amplifier via the multiplexing of the RF transmit line from the transmitter portion of the transceiver.



NOTES :

1. ALL POWER = PEAK
2. TUNING RANGE = 25 to 35 MHz
3. ALL LINES 50Ω IMPENDENCE
4. NOMINAL PLUSE WIDTH = 8μ sec (32μ sec MAX.)

Figure 8: Transmit Power Amplifier Block Diagram

2.2.2 Transmit Power Amplifier

The output of the radar transmitter in the transceiver is a short CW pulse of 10 dBm (10mW) power. This output must be boosted up to 70 dBm (10 kW) before being fed to the transmit antenna. This amplification is done in 3 steps all within the transmit power amplifier shown at the bottom of Figure 6. A block diagram of this amplifier is shown in Figure 8.

C-CORE's transmit power amplifier is a modified 1 kW linear power amplifier intended for CW amateur use in the CB bands. The unmodified amplifier is a model ALPHA 76CA supplied by ENRHORN TECHNOLOGICAL OPERATIONS INC. and modified for CODAR operation by C.T.I. and ERBTEC ENGINEERING INC.

The front end consists of a custom built solid state pre amplifier with an output of 100 W. The signal is then boosted up another 5 dB by an intermediate stage power amplifier custom built around a ceramic triode tube. The final outpout power amplifier consists of 3 tubes of this same type in parallel and provides the additional 15 dB gain required. A custom built control circuitry is included to monitor the operation of the unit and shut it down if any abnormal conditions exist. A DC status signal is returned to the transceiver by using the RF signal input cable as a bidirectional line. A bit in the transceiver status register on the SPI board indicates this status back to the 11/23 computer.

Many other amplifiers could be purchased and configured for the CODAR system. C-CORE's choice was made on the basis of reducing in-house custom engineering and eliminating the need for elaborate testing facilities.

Figure 9: Transmit Antenna at Cappahayden, Feb./82

2.2.3 Transmit Antenna

The transmit antenna array radiates the transmit radar pulse received from the transmit power amplifier via 200 ft. of cable. It consists of a three element Yagi antenna as discussed by Butt and Jeans (1981) and is shown in Figure 9 as used during C-CORE field trials.

C-CORE's antenna is a copy of NOAA's antenna designed by LAWRENCE LIVERMORE LABORATORIES and was built by INSTRUMAR LIMITED.

2.2.4 Receive Antenna Array

The receive antenna array provides the uniqueness of CODAR as a HF ground wave radar. It is a phase measuring array consisting of four 1/4 λ vertical antenna whips (marine CB antennas) arranged on the corners of a square. The diagonal of this square is slightly less (85%) than 1/2 the wavelength of the radar transmit frequency. Operation of this array is discussed further by Butt and Jeans (1981)

C-CORE's antenna array is a copy of the original NOAA design and was built by INSTRUMAR LTD. An additional aluminum frame provides for accurate and repeatable spacing of the array elements as shown in Figure 10.

2.2.5 Multiplexer Box

The multiplexer box shown at the top of Figure 6 contains the antenna multiplexer or antenna switcher, a pre-amplifier, a

Figure 10: Four Element Receive Antenna at Cappahayden, Feb./82

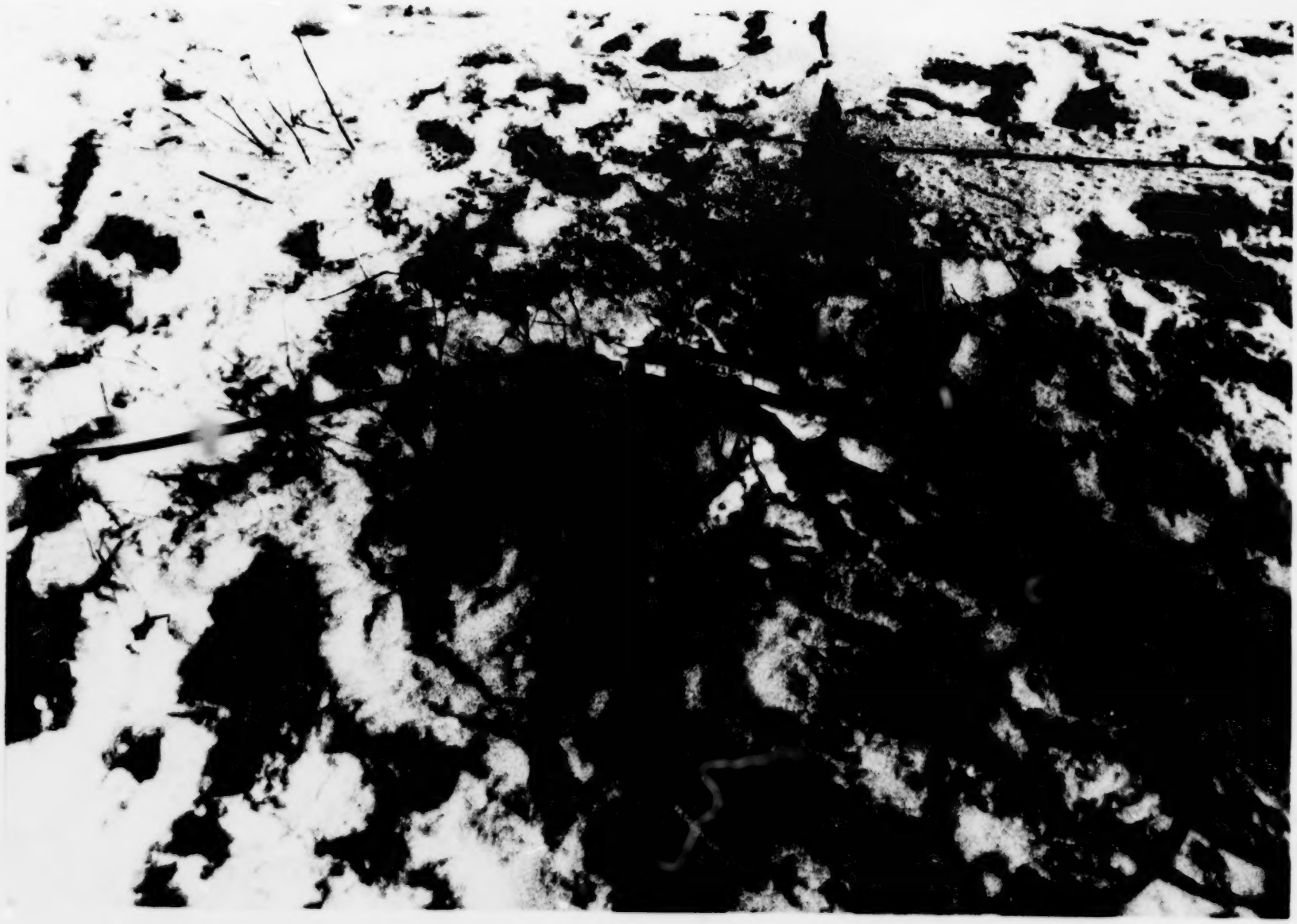


Figure 11: Multiplexer Box in Operation at Cappahayden, Feb./82

transmit - r[illegible]eive (TR) switch and a bandpass filter. The purpose of the mu[illegible]exer box is to switch sequentially from one antenna element t[illegible]her and to filter and boost the radar return signal for input to the transceiver via 200 ft. of coaxial cable.

The entire circuitry is solid-state and as shown connected in Figure 11 is housed in a rugged weather proof box located in the centre of the receive antenna array. It is basically an improved version of the design supplied by NOAA. It was designed and built by INSTRUMAR LIMITED.

Because the receive antenna array is a phase measuring array it is vital to equalize the time delays from each of the four receiving elements. As the return signals from these elements or whip antennas are summed in the multiplexer box it is only necessary to equalize the coaxial lines and internal circuit delays to this summing point. This, however, requires extensive care in the design of the multiplexer box and tedious testing in cutting the four cables running from the four receive antenna elements to the multiplexer box. The cross talk between the four sources of signal must also be minimized. The performance of the multiplexer and associated four cables is critical to successful operation of the CODAR system.

2.2.6 Transponder

A transponder is a radio receiver and transmitter which transmits an identifiable signal automatically whenever the proper interrogation signal or command has been received. A special low cost phase coherent transponder has been developed by NOAA to

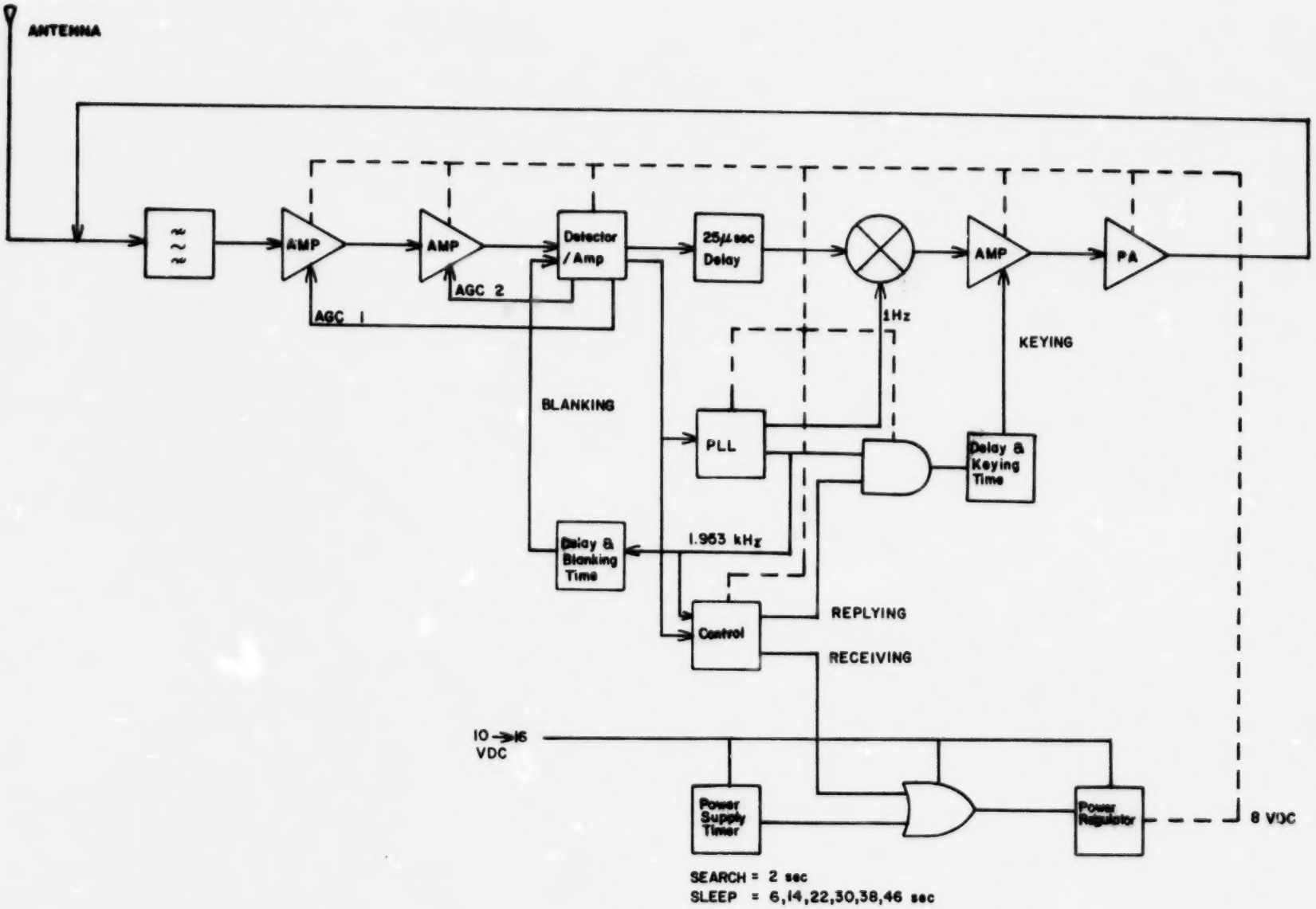


Figure 12: CODAR Transponder Block Diagram

allow the accurate tracking of the velocity and position of offshore platforms with the CODAR system.

Virtually hundreds of such transponders can be tracked simultaneously using a simple missing pulse code to interrogate or track each one in turn. The CODAR computer then records the return from each individual transponder and keeps an account of the resulting positional information.

C-CORE's transponder was developed jointly by ERBTEC ENGINEERING INC. and CTI of Colorado. It is a modified version of the original SEVEN OAKS RESEARCH design used by NOAA and is completely contained on one printed circuit board. A block diagram of C-CORE's transponder is shown in Figure 12. The receiver portion is a narrow band AGC (automatic gain control) amplifier tuned to 25.40 MHz. To conserve power and prevent the transponder from triggering on spurious signals and noise bursts, the transponder can be set up to turn on for 2 seconds and turn off for a fixed "sleep" interval and respond only to its unique address code. Once the transponder has been triggered it will stay on until the interrogation ends. These factors together with a low estimated production cost ($1,000.00 in large quantities) make it ideal for a disposable remote sensing tool. It is light enough and small enough to be mounted on a surface drifter and cheap enough to deploy in quantity on a field of floating sea ice and/or icebergs. See Evans et al. (1981) for a more comprehensive discussion.

2.2.7 HF Control Box

In March of 1982 a field trip to Pond Inlet, in the Canadian Arctic, was conducted to collect data on the attenuation of HF radio waves (specifically 25.40 MHz) over sea ice. Most of the CODAR radar equipment was utilized for this purpose. Because of the nature of this experiment and the logistics involved it was decided to replace the 11/23 computer with a control box to turn the CODAR transceiver on and off and adjust its gains. This was done by building a TTL based circuit hardwired to an operator panel as shown in Figure 6. The analogue output of the transceiver is monitored using an oscilloscope and wideband analogue tapes can be used to keep a permanent record.

The control box was also designed for use as a diagnostic tool for both field and lab operations. It has proved to be extremely valuable in this respect.

2.3 Specifications

Computer Terminal

Manufacturer : Digital Equipment Corp. (DEC)

Model # : VT100-AA

Size of Monitor : 36.83 cm H. X 45.72 cm W. X 36.20 cm D

Size of Keyboard : 8.89 cm H. X 45.72 cm W. X 20.32 cm D

Weight of Monitor : 15 kg

Weight of Keyboard : 2.0 kg

Power Supply : 120 VAC, 60 Hz nominal

Baud Rate : 50 to 19,200 bits/sec

Character Resolution : 132 X 24 with VT1XX-AB option

Options : VT1XX-AB advanced video option

Graphics Display Board

Manufacturer : Selanar Corp.

Model # : PL100

Size : 1.3 cm H. X 25.4 cm W. X 25.4 cm D.

Weight : 0.5 kg

Location : VT100 terminal card cage

Plot Method : vector and raster

Addressable Plot Area : 65.536 X 65,536 dots

Screen Size : 20.3 cm horizontal X 12.7 cm vertical

Viewable Screen Area : 1225 dots horizontal X 240 dots vertical

Character Size : 7 X 7 dots

Characters per Screen : 122 per line X 20 lines

Plotter

Manufacturer : Nicolet Zeta Corp

Model # : 1553

Size : 20.3 cm H. X 35.6 cm W. X 55.9 cm D.

Weight : 20.5 kg

Power Supply : 120 VAC, 60 Hz nominal

Interface : RS - 232

Baud Rate : 110 to 9600 bits/sec.

Buffer : 2048 bytes

Max. Plotting Speed : 35.9 cm/sec diagonally, 25.4 cm/sec in axes

Resolution : 6.35 cm

Plotting Area : 27.9 cm X 43.9 cm

Paper : fan fold perforated 21.6 cm X 27.9 cm

Computer

Manufacturer : Digital Equipment Corp. (DEC)

Model # : LSI 11/23

Mounting Box : BA11-NC/NE

Size : 13.2 cm H. X 48.3 cm W. X 57.8 cm D

Weight : 20 kg

Power Supply : 120 VAC, 60 Hz nominal

Backplane :"CD" configured Q bus with 9 quad height slots (H9273)

Memory : 2 X 64 K bytes (MSV11-DD)

Floating Point Instruction Chip : KEF11-AA

Multifunction Board : BDV11-AA (8 k bytes RAM + 2 serial ports)

RL/02 Disk Controller : RLV11K (2 boards)

Cypher Tape Controller : DILOG DQ130

Word Length : 16 bits

Max. Memory Addressable : 256 k bytes

Winchester Disk Drive

Manufacturer : Computer Memories Inc. (CMI)

Model # : CM5616

Size : 8.26 cm H. X 14.61 cm W. X 20.3 cm D.

Weight : 2.3 kg

Power Supply : 5VDC and 12 VDC regulated

Current Consumption : 0.9A @ 5VDC and 2.2A @ 12VDC

Formatted Memory Capacity : 12.6 M bytes

Disk Diameter : 13.34 cm (5 1/4 in.)

Number of Disks : 3

Max. Transfer Rate : 5M bits/sec.

Removable Disk Drive

Manufacturer: Digital Equipment Corp. (DEC)

Model # : RL102

Size: 27 cm H. X 48 cm W. X 63.5 cm D.

Weight: 33.75 kg

Power Supply: 120 VAC, 60 Hz nominal

Formatted Memory Capacity: 10.4 M bytes

Disk Diameter: 35.6 cm (14 in.)

Number of Disks: 1 (removable)

Max. Transfer Rate: 4.19 M bits/sec.

Magnetic Tape Drive

Manufacturer : Cypher Data Products

Model # : F880

Size : 22.23 cm H. X 43.18 cm W. X 55.88 cm D.

Weight : 36.3 kg

Power Supply : 120VAC, 60 Hz nominal

Formatted Memory Capacity : 10 M bytes with 6 in. reel

Tape Width : 1.27 cm (1/2 in.)

Reel Sizes : 17.78 to 26.67 cm diameter

Tape Read Speed : 25 ips

Loading : automatic front end vacum / manual

Bit Denisty : 1600 bpi

Transceiver

Manufacturer : Erbtec Engineering Inc. & Codar Tech. Inc. (CTI)

Model # : 700

Size : 13.0 cm H. X 43.2 cm W. X 52.7 cm D.

Weight : 20 kg

Power Supply : 120 VAC, 60 Hz

Transmit Output Power : 10 dBm (into 50 Ω)

Receive Sensitivity : -103 dBm (tangential)

Pulse Width : 8 to 32 μ sec. nominal (programmable in 8 μ sec. steps)

Pulse Repetition Rate : 1.953 kHz

Input/Ouput Transmit Frequency : 25 to 26 MHz (50 kHz steps)

Digital Output : 12 bits data, 4 bits control

Digital Sampling Rate : 125 kHz

Analogue Output : + 12 V

Output Mode : baseband in-phase and quadrature (I & Q)

Dynamic Range : 101 dB

Transmit Power Amplifier

Manufacturer : Erbtec Engineering Inc & Codar Tech. Inc (CTI)

Model # : 600

Size : 19 cm H. X 43 cm W. X 38 cm D.

Weight : 30 kg

Power Supply : 120 VAC, 60 Hz

Input Peak Power : 10 dBm

Output Peak Power : 70 dBm into 50Ω

Input Pulse Width : 8 to 32 U sec. nominal

Transmit Frequency : 25 to 35 MHz

Output Bandwidth : 250 kHz (with 8 U sec pulse)

Preamp. Drive Device : solid state

Intermediate Amp. Drive Device : ceramic triode tube

Output Drive Device : ceramic tubes in parallel

Transmit Antenna

Manufacturer : Instrumar Limited

Type : 3 element Yagi

Vertical Elements : 3 X 2.86 cm O.D.

Director Height : 2.37 m

Driver Height : 2.92 m

Reflector Height : 3.14 m

Director - Driver Spacing : 0.627 m

Driver - Reflector Spacing : 2.70 m

3 dB Beamwidth : 180°

Impedance : 50 Ω nominal

Connector Type : UG 560/U

Receiver Antenna Array

Manufacturer : INSTRUMAR Limited

Type : phase measuring array

Vertical Elements : 4 X 284.5 cm fibreglass CB whip antenna

Horizontal Ground Plane : 16 X 259.1 cm steel whip antennas

Element Spacing : corners of square (359.2 cm X 359.2 cm)

Connector Type : UG58 A/U (4)

Impedance : 50 Ω nominal

Multiplexer Box

Manufacturer : INSTRUMAR Limited

Size : 8.9 cm H. X 15.9 cm W. X 15.9 cm D.

Weight : 2.3 kg

Power Supply : 30VDC & -24VDC unregulated

Current Consumption : 400 MA @ 30 VDC & 100 MA @ -24 VDC

Antenna Inputs : 4 (type N connectors)

Control : digital (TTL)

Gain : 10.7 dB + 0.5 dB (20 - 30 MHz) (no filter)

Optional Filter 3dB Bandwidth : 23.7 to 28.4 MHz

Optional Filter Insertion loss : 1.5 dB at 25.4 MHz

Feed Through Isolation : 55 dB min.

Blanking Isolation : 73 dB min.

RF Impedance : 50 Ω

Max. RF Input Power : +24 dBm max.

RF Output Power : +28 dBm (1 dB compression)

Switching Rate : 2 kHz nominal

Transponder

Manufacturer : Erbtec Engineering Inc & Codar Tech. Inc. (CTI)

Model # : 1100

Size : 2.0 cm H. X 12.7 cm W. X 30.5 cm D.

Weight : 0.5 kg

Power Supply : 10 to 16 VDC unregulated

Current Consumption : 100 MA @ 10 to 16 VDC

Output Power : 33 dBm (2 watts) constant into 50 Ω

Sensitivity : -85 dBm

Input Pulse Width : 16 U sec. nominal

Input Pulse Repetition Rate : 2 kHz + 200 Hz

Output Pulse Repetition Rate : input pulse repetition rate

Input Frequency : 25.400 MHz +/-1 kHz min.

Output Pulse Width : 16 U sec. nominal (constant)

Output Frequency : input frequency + 1 Hz modulation (constant)

Transponder Delay : 25 U sec. nominal (constant)

Temperature Range : 20^{o} to -25^{o}o C

Search Time : 2 sec. nominal

Sleep Time : 6, 14, 22, 30, 38, 46 sec. strap selectable

Antenna : monostatic, 50 Ω impedance

CODAR Power Consumption

The power consumption specifications given by most of the manufacturers mentioned in this report are very conservative. They tend to be over rated considerably.

The following current measurements were made on the CODAR equipment in preparation for the CAPPAHAYDEN field trials (section 5):

SYSTEMS	CURRENT (AMPS)
RL02 Disc Drive	-
VT100 Termminal	-
Cipher Tape Drive	-
LSI 11/23 Computer	-
Sub-total	5.5 running
Sub-total (peak)	7.0 surge during disc drive start-up
465B Oscilliscope	-
Lear Siegler Terminal	-
700 Receiver	-
600 Transmitter	-
HF Control Box	-
Sub Total	3.5 standby
	5.5 during 8 μ sec. transmit
Sub Total (peak)	6.5 during 16 μ sec. transmit
TOTAL (peak)	13.5

NOTE: All currents at 120 VAC

3.0 SOFTWARE DESCRIPTION

The CODAR computer system software consists of two major sections; 'Data Acquisition' and 'Data Interpretation'. The data acquisition software of course, is an integral part of system operation during raw data collection. The format of this software is designed to restrict user options and keep operational complexity to a minimum.

The data interpretation software, on the other hand, varies in complexity and user interaction with data processing requirements. This may be anything from surface current mapping to transponder target and sea state analysis.

This report will deal only with the surface current mapping application of the CODAR System. Software processes are referenced with program code upper case type. (eg: DATA, COMMON, PANEL etc.)

3.1 Data Acquisition

The data acquisition software runs under RSX 11M or RSX-11S (memory only) operating system and it makes use of RSX "multitasking"* features. This features allows the running of several tasks or programs at what appears to be the same time. This is accomplished through a prioritization scheme which will run the program or task of highest priority first. This ensures

* A task refers to a program to be scheduled for execution. For example, when there are five programs to be run, the computer has five tasks to schedule and complete.

that, above all, the data will be collected. Due to many system constraints such as computer memory limitations and input/output time lags for tape drives, the early software packages were subject to stringent timing considerations. For example, with a 25 ips tape drive and the CTI Signal Processing Interface (SPI), the time required to write a full buffer of data to tape had to be less than that required for the next half buffer of data from the SPI to be acquired. This time constraint required that the automatic retry for tape errors be disabled.

While many of these constraints are no longer as important with the advent of the LSI 11/23 and field usable disc drives, the C-CORE package remains about the same, with major changes having taken place with the display format.

While both NOAA and CTI have made some recent changes the basic form of their packages also remain the same.

The Data Acquisition package consists of the tasks as shown in Figure 13. Each one of these is briefly discussed in the following sections.

3.1.1 Common Storage

There are two principal storage areas (in memory) used in the data acquisition system software. One, named PANEL holds all the data for the control console and status display task. (ie: error flags, status data, etc.)

The other, named COMMON holds similar data but for the other tasks in the system. It also holds the tape header to be written

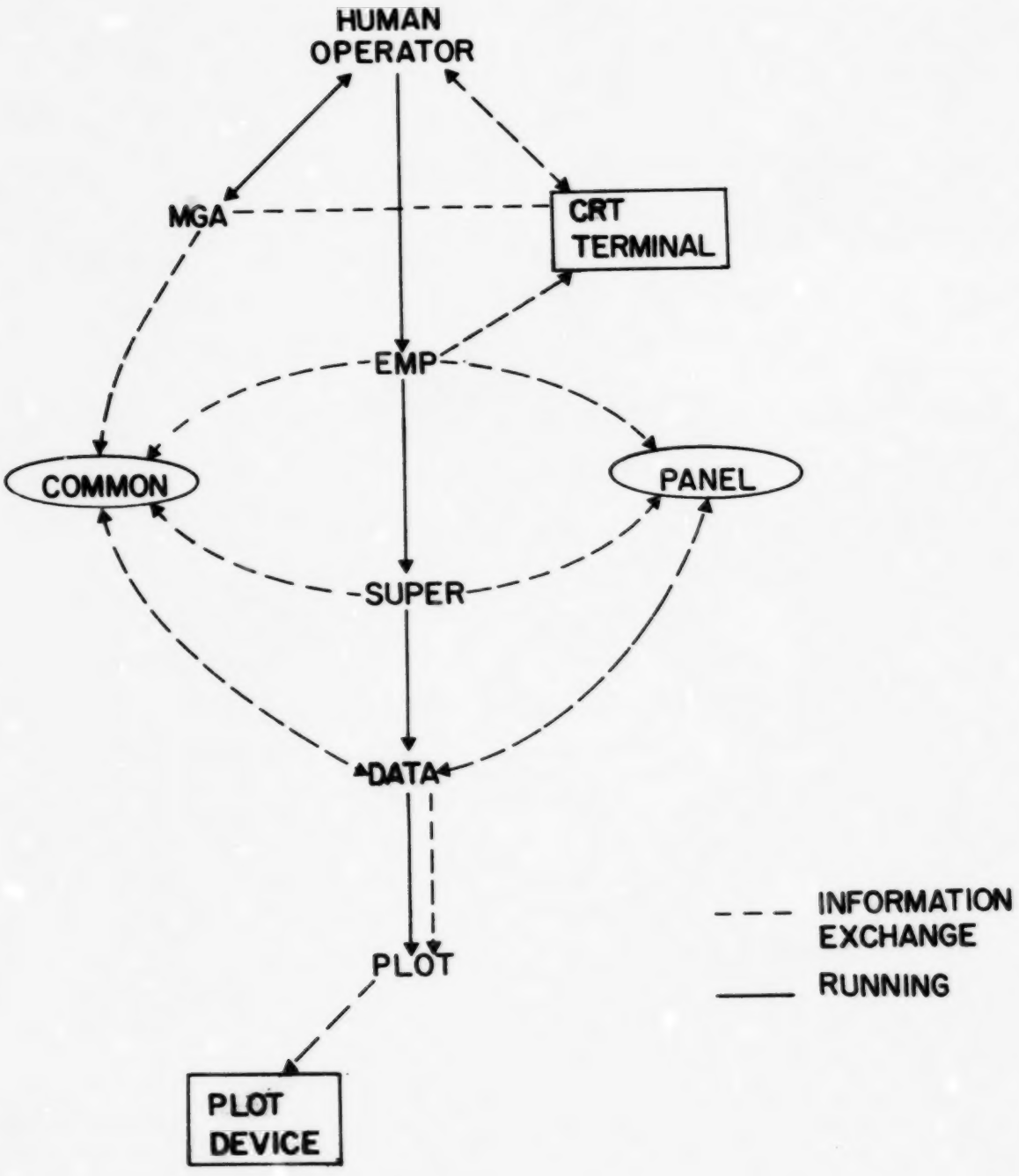


Figure 13: Data Acquisition Task Interaction Chart

at the beginning of each run. This header holds all the site information, run parameters, etc.

3.1.2 Emulating Panel (EMP)

EMP is the name of the task which allows communication between the human operator and the system.

Upon start-up, EMP requests information about the site, such as latitude, longitude, antenna boresight, as well as scheduling information for the runs to be performed. Scheduling may be automatic or manual depending upon the operator's wishes. In the manual mode, the system is dormant until a 'GO' command is issued from the control console. In the auto mode, runs occur at time intervals set by the operator but can be overridden by issuing the 'GO' command. An operator is still required to change tapes.

EMP performs no actual data collection, it merely inputs the operator's data, sets the required parameters in the COMMON and PANEL areas and updates a status display.

It is interesting to note that EMP is an acronym for Panel Emulator. It was initially intended that operator input be from a hardwired panel with thumbwheels and switches. EMP was written to simulate a panel but over a period of time, the panel idea has been discarded in favour of the CRT/control console concept.

3.1.3 Supervisor (SUPER)

SUPER is the supervisor task. Its functions are to implement the scheduling and monitor the SPI and computer periperals.

When a 'GO' command is issued, SUPER verifies that all is okay, and takes care of the resetting of time displays. It then runs both the data and real-time plot tasks.

For example, if the system is running in auto-schedule mode, and the operator requires a run to be performed, he issues the 'GO' command. SUPER decides if there is enough time between the present and the next run time before allowing DATA and PLOT to be run. If not, SUPER reschedules the next automatic run so that the desired extra run can be squeezed in.

3.1.4 DATA

DATA is the most critical piece of software in the whole package. It accepts data from the SPI and writes it to magtape. It also runs and transmits data to be PLOT task.

DATA uses a 1.5 buffer scheme. That is, it contains a large 'main' buffer and a 'shuffle' buffer one half as large. The main buffer holds the data to be written to tape. While the tape writing is in progress, the shuffle buffer is used. After the tape action is finished, the shuffle buffered data is transferred to the main buffer and so on.

3.1.5 PLOT

The PLOT task is essentially a system monitoring program. It displays plots of either time series or spectra for a desired range cell and antenna during real-time operation. (see section 5.2 for figure reference and further description of actual data plot). From the plots, the operator can make some estimates

regarding the quality of the data being obtained. C-CORE uses a 'Selanar' graphics board as described in section 2.1.2 for this purpose. Although different from NOAA's, it was simple to modify the plotting package to accommodate this change as it used only one device dependent sub-program.

While, at present, the system console and plot devices, are separate units, it is feasible to integrate the two functions into one unit. This would decrease the cost and complexity of the system as the requirement for two terminals and certain EMP functions would be eliminated.

3.1.6 Manual Gain (MGA)

MGA is the task used to set the receiver gains. It is a totally manual data entry program, interlocked to the DATA task so that the gains cannot be altered during a run. The radar must be transmitting while the gains are adjusted. During this time data cannot be collected.

MGA is written to use the VT100 display and escape sequence handling capabilities. The gains for the 64 range cells (displayed as 0 - 63) are displayed alphanumerically (see Figure 14) and are altered by the use of the program function (PF) keys as well as the cursor control keys. (see Figure 15). The left/right cursor control keys position the user at any one of the 64 range cells by stepping through one at a time. The up/down cursor control keys increment and decrement the gain valve for

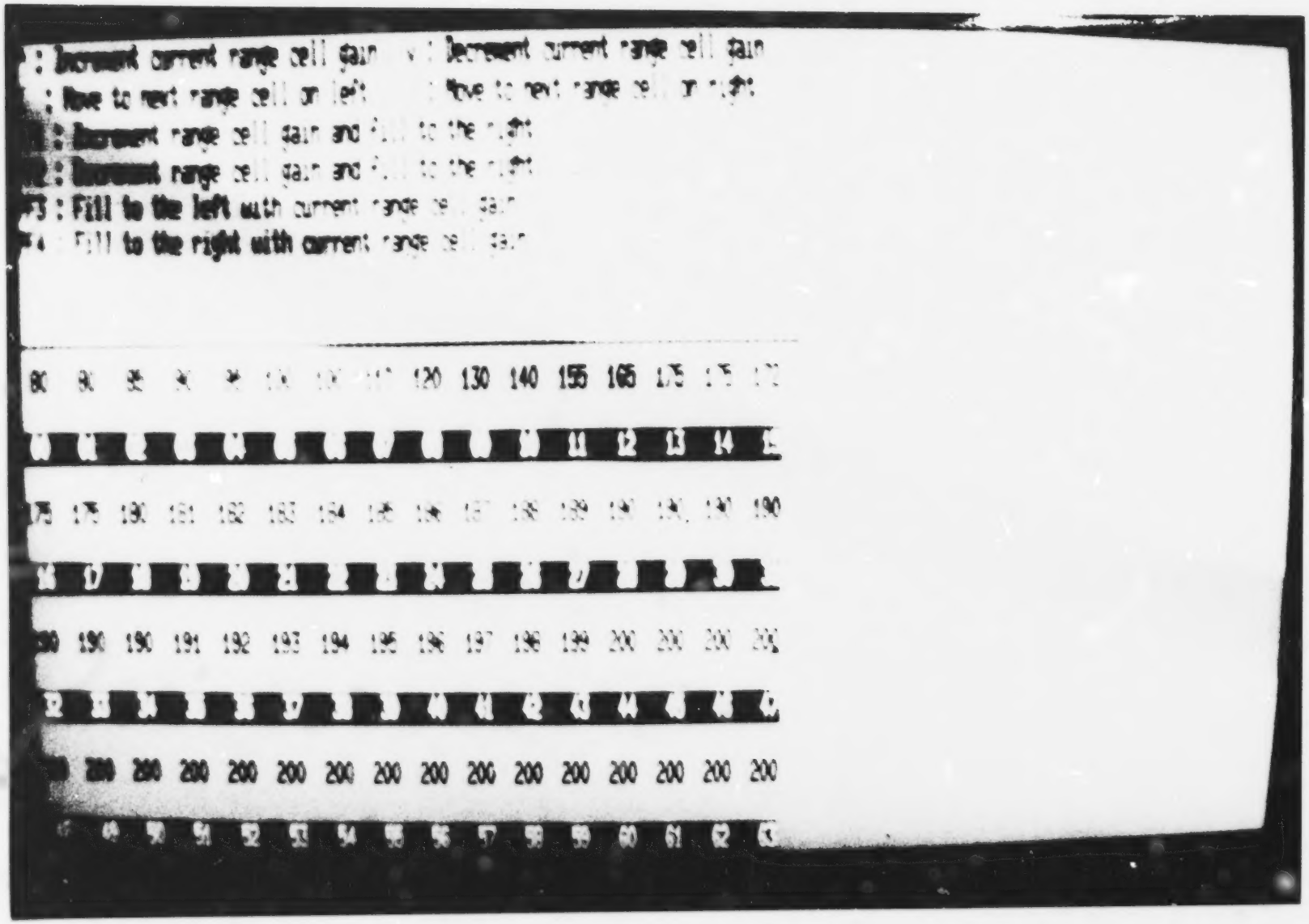

: Increment current range cell gain
: Move to next range cell on left
: Increment range cell gain and fill to the right
: Increment range cell gain and fill to the right
F3 : Fill to the left with current range cell gain
F4 : Fill to the right with current range cell gain
80 90 100 110 120 130 140 155 165 175
175 180 181 182 183 184 190
190 190 191 192 193 194 195 196 197 198 199 200 200 200 200
200 200 200 200 200 200 200 200 200 200 200 200 200 200 200

Figure 14: Photograph of Display CRT Showing Output of Manual Gain Program

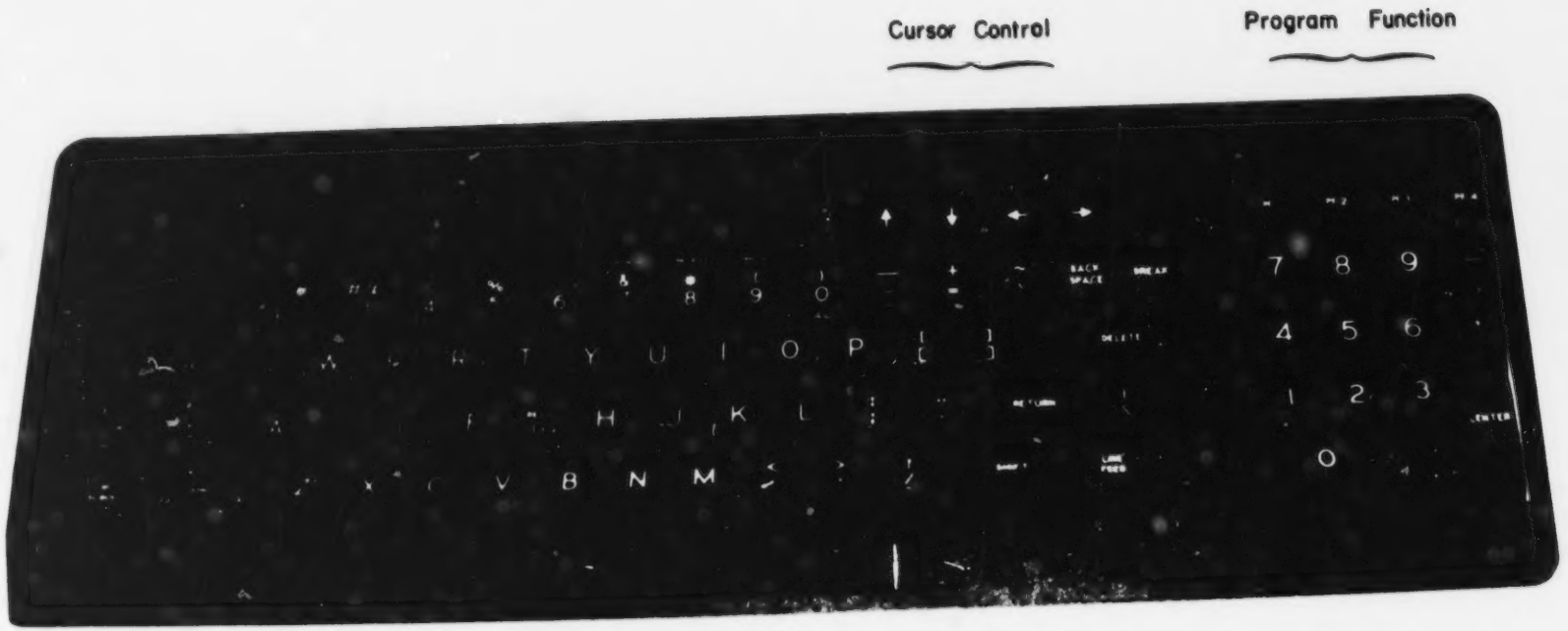


Figure 15: Photograph of Display Console Showing Keyboard Layout

each cell. The program function keys allow for filling all range cell gains to the left or right of cursor.

3.2 Data Interpretation

The C-CORE CODAR data interpretation software's purpose is to generate radial vector maps for a single site CODAR system.

All software is written in DEC Fortran IV plus and can be run on any computer supporting this language.

The package developed by C-CORE is based on software obtained from NOAA, but C-CORE's data access approach is completely different. It should be noted that the NOAA package was only used as a guide during development

The C-CORE interpretation package consists of four major stages as depicted in Figure 16. In the following sections, each of these stages will be discussed.

3.2.1 DUMP

This program facilitates the reorganization of the "raw" magnetic tape data to a format suitable for current map processing.

It creates a direct access disc file and reformats the raw data tape shown in Figure 17 and transfers to the disc file as shown in Figure 18.

This is a straight I/O program with no number processing. The time required for this transfer is approximately 6 seconds per tape record. There are 512 records for a 36 minute data file.

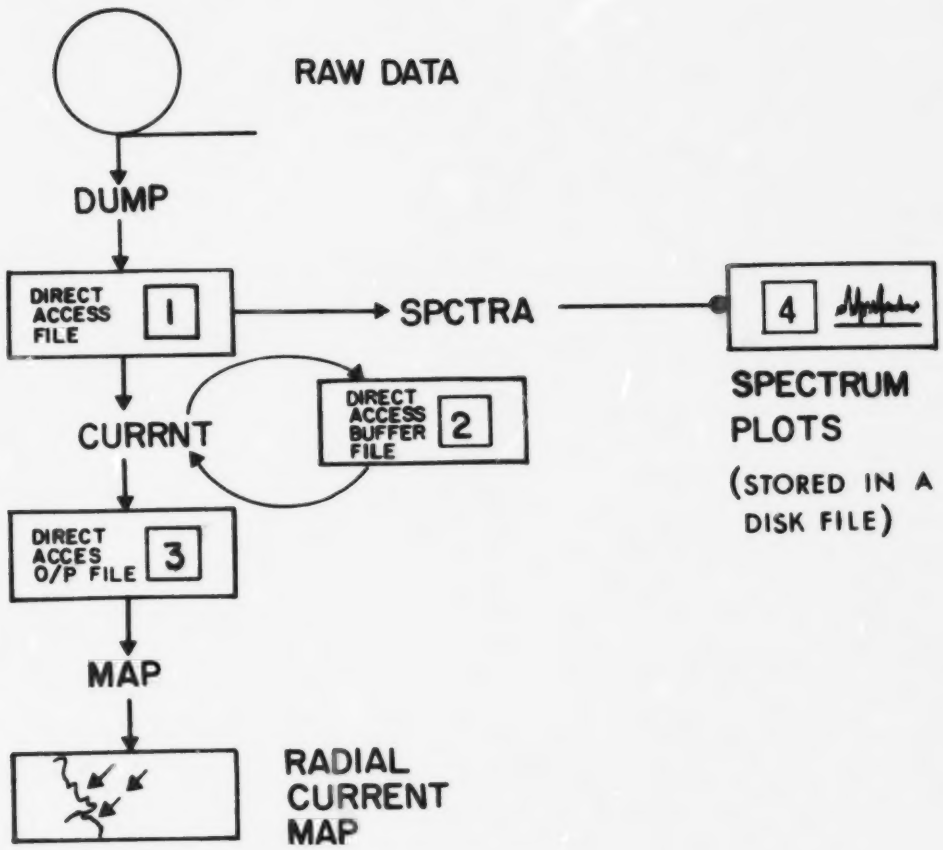


Figure 16: Data Interpretation Flow Chart

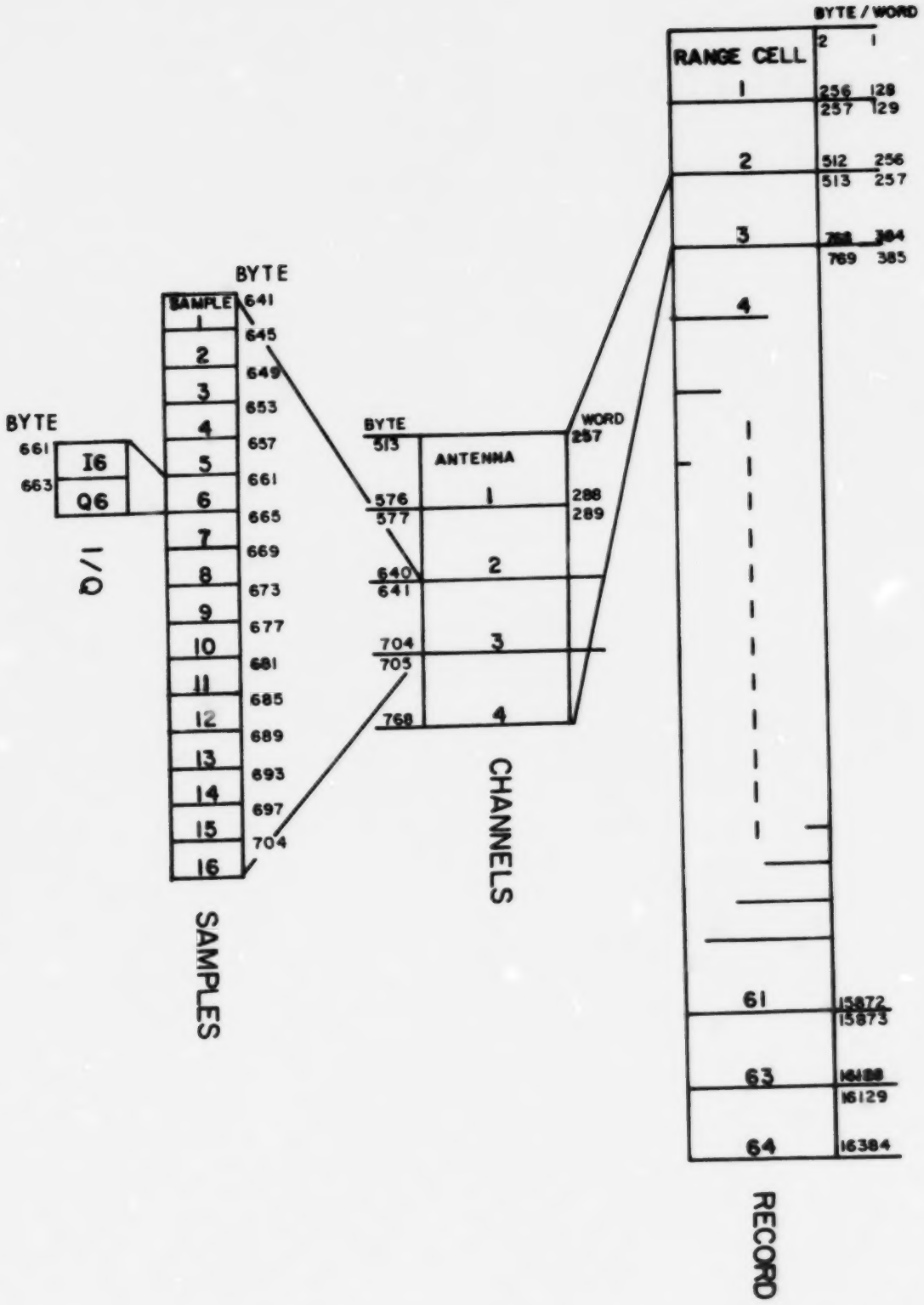


Figure 17: Raw Tape Data File Format

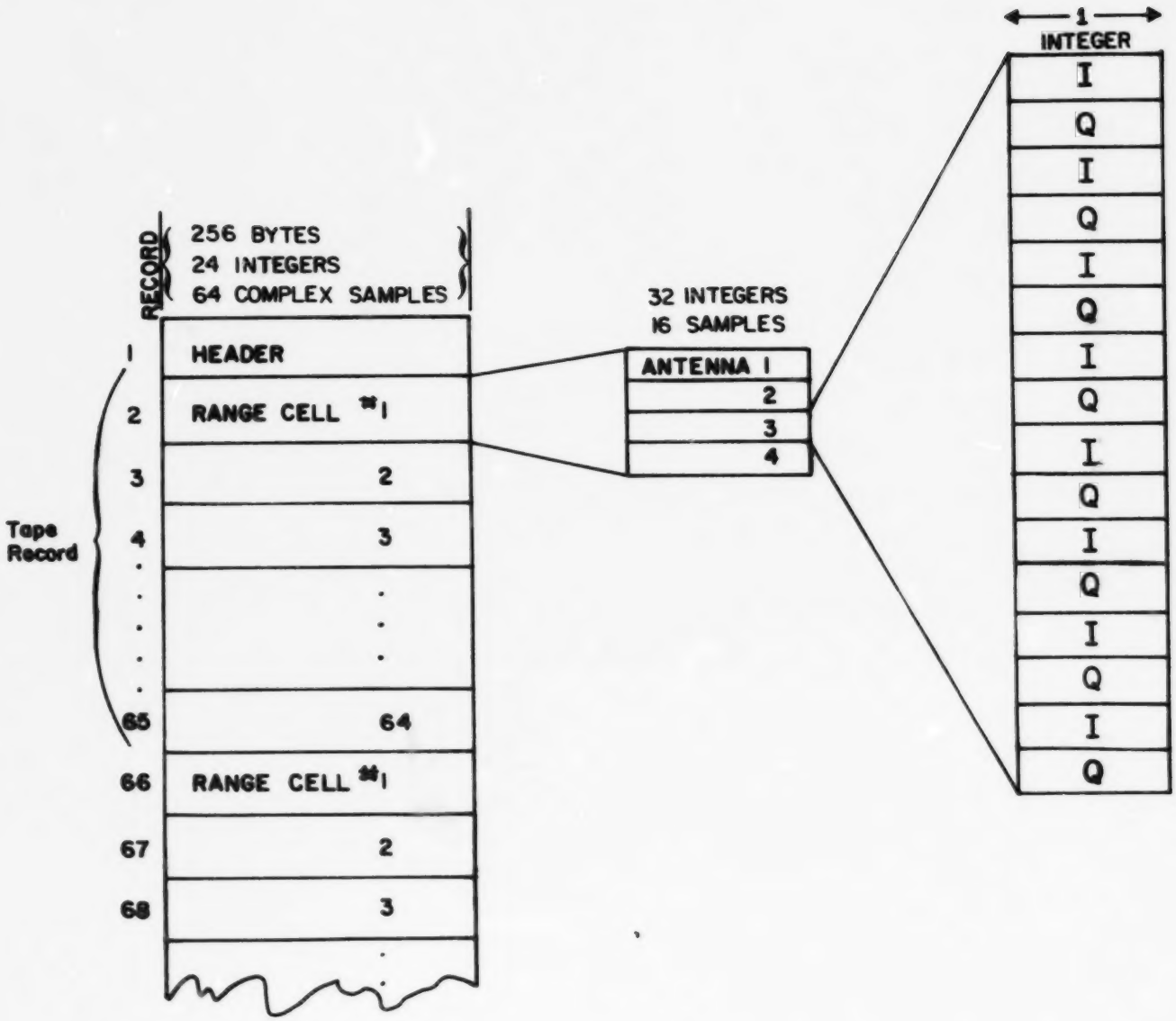


Figure 18: Disk Raw Data File Format

3.2.2 Spectra (SPCTRA)

This program produces Bragg magnitude spectra from CODAR time series data as shown in Figure 19. There are two versions of this program; one is for hard copy plotting to a 'Zeta Plotter' and another for plotting spectra on the VT100/Selanar combination. Each version is structually the same except for the plotting library routines. A hierachy chart of SPCTRA is shown in Figure 20.

The input to this program is a file created through DUMP. Its output is a file containing all the plotter code required to generate the plot. The program operates as follows:

1. Initialize all program variables and obtain user dependent information, such as antenna, range cells to plot and FFT size. (INITPL).

2. Obtain site information and radar operating parameters from input file header (RHDRPL).

3. Obtain required time series (INPTPL).

4. Apply Fourier transform (FFT). (called from PLOTC)

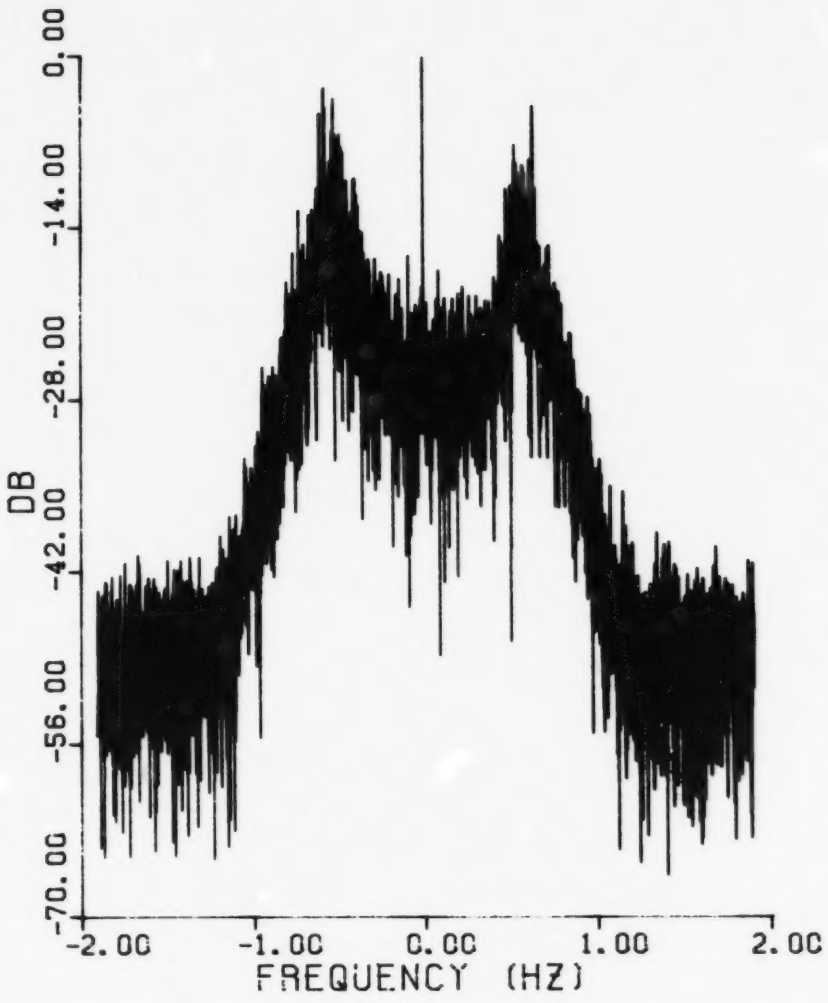
5. Switch the sides of the spectrum (FLIP) so that visual presentation is correct. (called from PLOTC)

6. Plot out the spectra (PLOTC)

7. Annotate the plot with the necessary information (PRTHDR).

3.2.3 Current (CURRNT)

CURRNT is the program which calculates the radial surface current vectors. Its input is from a disk file created through



Antenna: 1 Range Cell: 20
Run Time: 22-FEB-82 20:30 :
Latitude: 46 51 40
Longitude: -52 56 45
Antenna Boresight: 112.00
Frequency (MHz): 25.40
Pulse Width (us): 8.00
FFT Size (points): 2048

Figure 19: Ocean Doppler Spectrum Produced from C-CORE CODAR Field Data

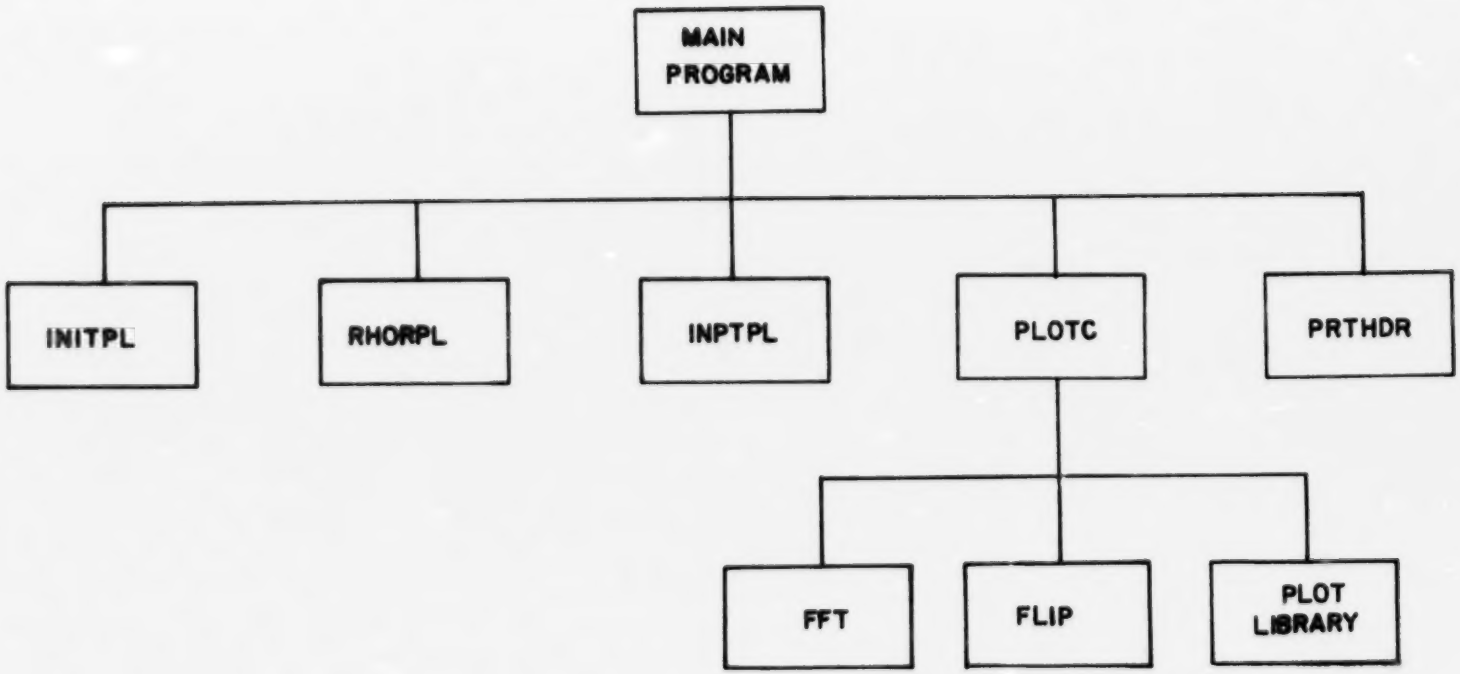


Figure 20: Spectra Plotting Software Hierarchy Chart

DUMP and its output is a disk file whose format is given in Figure 21. This file contains the calculated radial current vectors and weighting factors. This weighting factor is an estimated measure of the validity of the data.

CURRNT also utilizes another disk file as a temporary storage area for time series and discrete Fourier transforms. This file is simply a 'scratch pad' and disappears when the program is complete.

A hierarchy chart of the program is given in Figure 22. This chart shows the structure of CURRNT as well as the sequencing of the subroutines.

The program operates as follows:

1. Initialize all program variables and obtain user dependent information such as number of range cells to process, FFT size etc. (INITSS)

2. Read the input file header and extract necessary site information and radar operating parameters (RHEADR).

3. Using the header and user supplied data, calculate various processing data, such as Bragg wave phase velocity, velocity resolution of the FFT, window limit for the first order Bragg peaks etc. (WINDW).

4. Write a header to the output file holding information similar to the header read in, but with additional data such as FFT size, number of processed range cells, etc. (WHEADR)

5. Input the time series for the current range cell and store it in the buffer file (INPTSS).

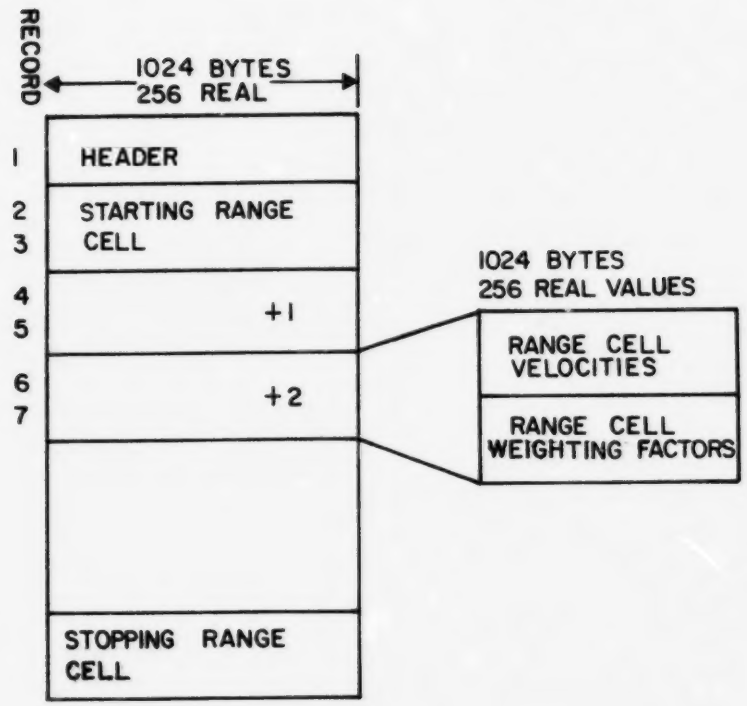


Figure 21: Radial Velocity File Format

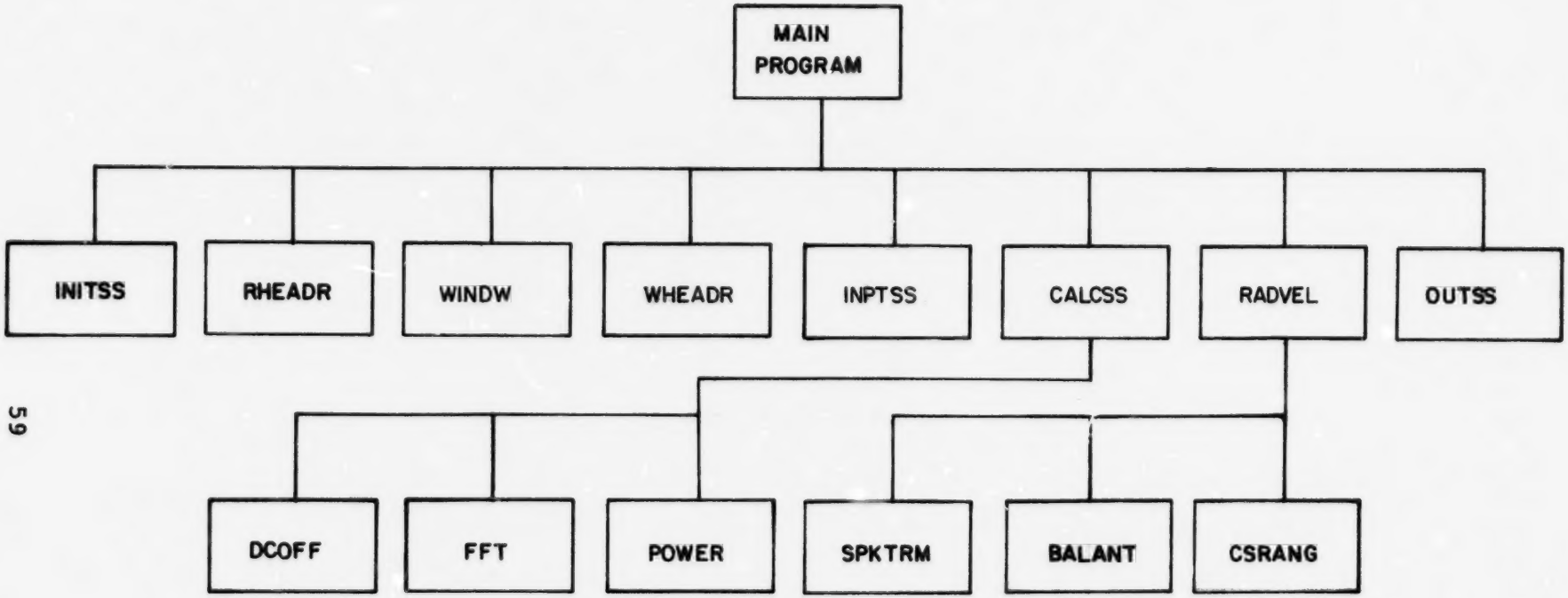


Figure 22: Radial Current Vector Calculation Software Hierarchy Chart

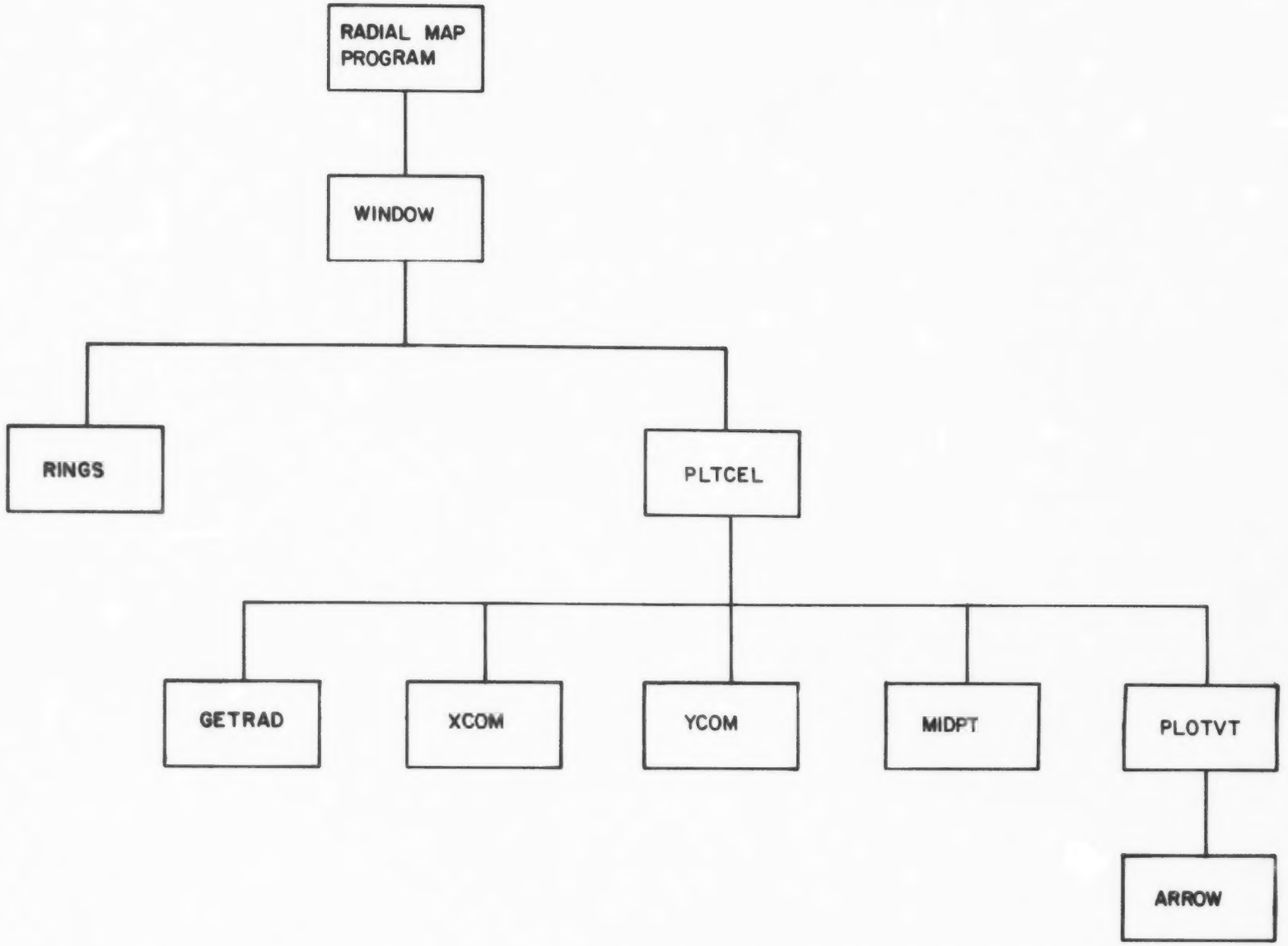


Figure 23: Radial Velocity Map Program Hierarchy Chart

6. Obtain the time series, remove any D.C. component from the signal (DCOFF), Fourier transform the data (FFT), determine average ocean return and noise (POWER) and write this back out to the buffer file. This step falls fully into subroutine CALCSS.

7. For the first order Bragg peaks, calculate the Doppler and angles of arrival for the Fourier Transform points lying in this area (RADVEL). This involves checking for a good spectrum (SPKTRM), balancing antenna amplitudes (BALANT) and determining arrival angles (CSRANG).

8. Write the velocity vectors and weighting factors to the output file (OUTSS).

Repeat steps 4 through 8 until all specified range cells are processed.

For a 1024 point series, 256 angle bins, the time required to perform the current calculations is approximately 2.5 minutes per range annulus. This time includes all I/O operations.

3.2.4 Radial Current Vector Mapping (MAP)

This program accepts input from the data file created by CURRNT and generates a plot of the current vectors. The user inputs the angles and range cells to be plotted as well as a weighting factor threshold. This weighting factor threshold is used to avoid plotting vectors whose quality is below acceptable limits.

The structure of the program is given in the hierarchy chart of Figure 23. The program operates as follows:

1. Obtain user input data such as angles and range cells to be plotted and get the weighting factor cut off threshold. Input the velocity vectors and weighting factors from the input file (WINDOW).

2. Plot range annulus delimiting rings if requested by the user (RINGS).

3. Plot out the radial vectors for the desired ranges and angles (PLTCEL). This involves converting the input angles to radians as the system trigonometric calculations are performed in radians (GETRAD); converting the polar coordinates of each angle bin (range, angle) to rectangular co-ordinates (x,y) for the plots (XCOM, YCOM); determining the midpoint of the range cell in plotter co-ordinates (MIDPT); plotting a vector of a scaled size, representing magnitude, centred at the range cell midpoint (PLOTVT); and putting an arrowhead on the vector to indicate current direction (ARROW).

The above steps are executed for all the range cells specified by the user. A map produced under this program is referenced in section 6.0, Preliminary Data Analysis.

3.3 Comments

The data acquisition package as it presently exists is a proven system. It does, however have several draw backs.

It is essentially a computer core memory package (written for RSX-11S). While C-CORE did operate it from a disk based system, once it was up and running the disk was no longer used. By utilizing the high speed, larger memory access of a disk based

system, a much more efficient system could evolve. The use of a disk would also reduce the strict time constraints presently on the system due to tape transfers and allow for the retry option for tape error correction.

The present C-CORE system has no automatic gain setting algorithm. As sea conditions and/or local noise vary from run to run the gains have to be constantly adjusted. This can be very time consuming and prevents auto scheduling for extended periods. The manner of manually setting the gains can also be improved. Each range cell gain has to be entered and monitored through an alphanumeric display. Gain effects are monitored by A-scope. A digital display of peak and r.m.s. values of the signal per range cell would provide more efficient feedback response.

The plotting of spectra and time series have no "save" feature, i.e. if one wishes to examine a plot, there is no facility for dumping it to a hard copy unit or storing it for future reference.

The data interpretation software, written at C-CORE, is based upon that used by NOAA. During its development and use, several questions have arisen regarding certain aspects of the implementation. Primarily, these are the use of signal to noise thresholding techniques and a so-called 'quality' factor that require some user interaction. These points will be investigated further and be reported in future work.

The interpretation process consists largely of Input/Output operations that are very time consuming and will affect real-time operation. Transfer of the acquisition process to a disk based

interactive operation in real-time to facilitate improved data management could decrease vector processing time by up to 70%.

4.0 TRIP REPORTS

The following sections discuss briefly each significant program requiring travel for purposes of evaluation and development of the C-CORE CODAR hardware and software systems. C-CORE field trials are discussed in Section 5.0.

4.1 C.T.I. - Equipment Inspection

Two of the program staff visited CODAR Technology Inc. in October to ensure that the equipment production was proceeding to our satisfaction. Appropriate testing programs were discussed and customs papers put in order to assist expedient transfer to our labs.

While in Boulder we visited the WPL group at NOAA and confirmed that NOAA's new version of CODAR data acquisition software was an improvement over the existing development. However, it was too dedicated to field disk operation and certain data processing functions for use as an initial research tool. Therefore, it was decided to contract CTI to supply an operational version of the old software to C-CORE with modifications incorporating a special graphics package to permit spectral plotting on the computer terminal display. Initially, for the purposes of the DSS contract, a separate terminal was used for display. Eventually, both operator commands and spectral display will be multiplexed on the same CRT reducing field hardware requirements. The NOAA system still uses a separate dedicated display package requiring custom engineering in development.

Contact was made with a British research and engineering group while in Boulder. They were in town to discuss acquisition of a CODAR system for use in coastal engineering programs. They seemed pleased with the technology they saw and convinced us further that acquisition of CODAR technology was still the best initial step toward developing an HF coastal ocean research program in Canada.

4.2 NOAA - California Field Trials Software Modification

In January 1982, the program's software engineer visited a NOAA test site at Iversen Point in California. NOAA had acquired and was testing a new version of the CODAR system (both hardware and software).

Observations made during the visit included:

- NOAA reformats data from the SPI and produces spectra in the field (see recommendations). The system utilizes disk based memory and a DEC LSI 11/23 with a full complement of memory (256 kilobytes).
- NOAA now uses a rigid receiving antenna system constructed of aluminum pipe.
- Console functions were VT100 oriented but the plotting is still performed on the custom NOAA graphics box.

Discussions were held with NOAA personnel regarding the acquisition of this NOAA software package (see recommendations)

4.3 C.T.I. - Data Acquisition Software Development

During the same trip a visit was paid to Codar Technology Inc. in Boulder to ensure that the data acquisition software being supplied was operable on the C-CORE System.

While there, the software for the graphics display was modified to suit the Selanar board which had been brought along for this purpose.

A tape "cartridge" system was tested to determine the feasibility of using it with the C-CORE CODAR System. It was found that the time delay between track changes was too long for data acquisition software to operate (see section 2.1.5).

A working version of the data acquisition software as well as a bootable system (RSX-11M) were obtained on Mag Tape.

A Lear Siegler ADM 3A CRT terminal was also supplied by C.T.I. for use as the console device.

5.0 C-CORE CODAR OPERATIONAL TRIALS

Several field tests were scheduled under this hardware development phase. They focussed principally on one site CODAR hardware performance with the following main objectives:

A. To test qualitatively individual component operation when connected as part of a complete one site radar. The system specifications are presented in more detail in section 2.3 of this report.

B. To verify basic operational capability as a single site CODAR under computer system control.

C. To verify Doppler measurement capability of the hardware utilizing a phase-locked HF transponder.

D. To verify capability to function satisfactorily on power from a portable gasoline generator.

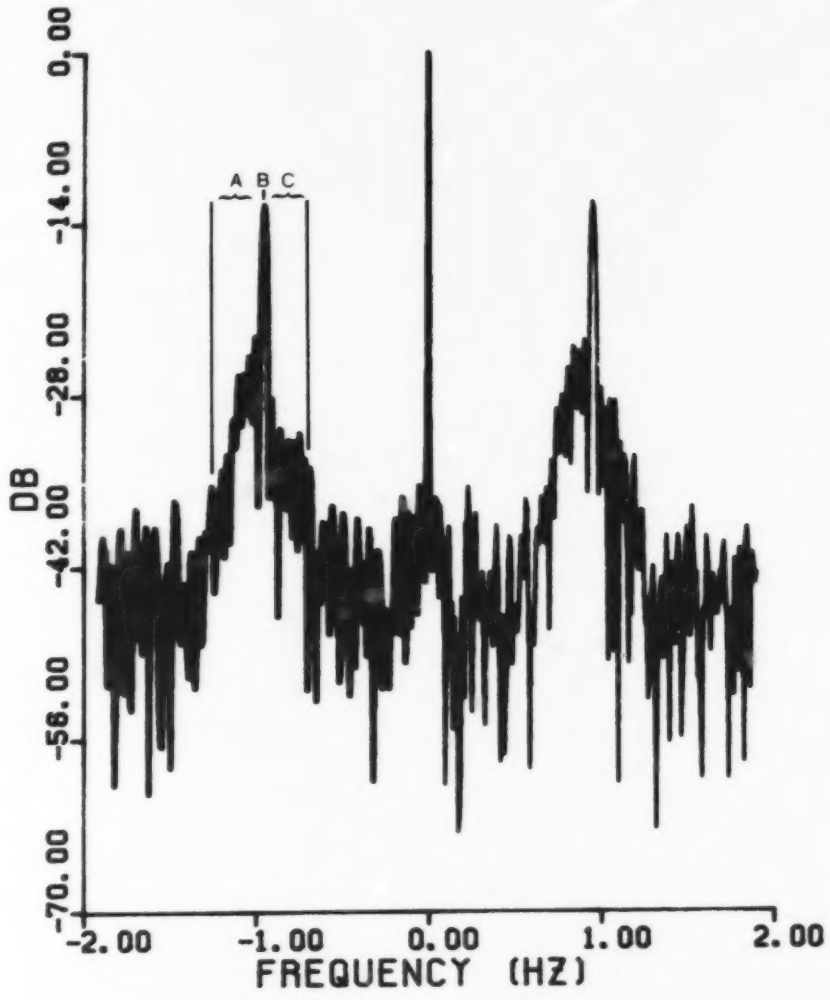
E. To test C-CORE Control Box and rehearse propagation experiments to be performed over Arctic sea ice in March 1982 with the basic radar equipment (ie: no computer) and an HF Doppler transponder.

5.1 Initial Hardware Tests

The initial hardware tests took place February 15th to the 17th from C-CORE's facility on the Memorial University of Newfoundland's campus.

The radar transmission equipment was configured as a one site CODAR in a few hours with no major difficulties.

The Department of Communications had granted special permission to the study to permit experimental operation of the



Antenna: 3 Range Cell: 7
Run Time: 17-FEB-82 12:32 :
Latitude: 0 0 0
Longitude: 0 0 0
Antenna Boresight: 0.00
Frequency (MHz): 25.40
Pulse Width (us): 16.00
FFT Size (points): 512

Figure 24: Doppler Spectrum Plot of Local Transponder Run

Part "A" - Moving away from the radar
Point "B" - Stationary
Part "C" - Moving towards the radar

radar equipment on a non-interference basis. All transmissions were kept to a few minutes with the exception of the transponder velocity tests which required 9 minute transmissions on two occcasions.

Testing continued for two days, during which power consumption, software operation and all hardware operational requirements were verified, monitored and compared with expected performance specifications previously described.

A phase-locked Doppler transponder with built-in ±1Hz carrier modulation was used to examine the velocity performance in a qualitative, semi-quantitative fashion. A road was chosen in the city that ran on a radial path from the radar. The transponder was subsequently mounted on the roof of an automobile and driven slowly away, then stopped and returned towards the radar during a 9 minute, 2048 point CODAR data run. The complex Doppler frequency spectrum of this time series data is shown in Figure 24. Part "A" represents the history of the transponder velocity away from the radar, Point "B" indicates that it stopped and part "C" represents the motion towards the radar. The smearing (ie: width of areas "A" and "C") of the signal spectrum represents the velocity variation during the run. Note that with the exception of noise influence, the right side of the spectrum is the same a the left.

Before heading off on our field operations, a preliminary examination of power consumption indicated that start-up surge currents and 16 microsecond pulse width transmission would require a 2kw 115 VAC power generator for reliable operation in the field.

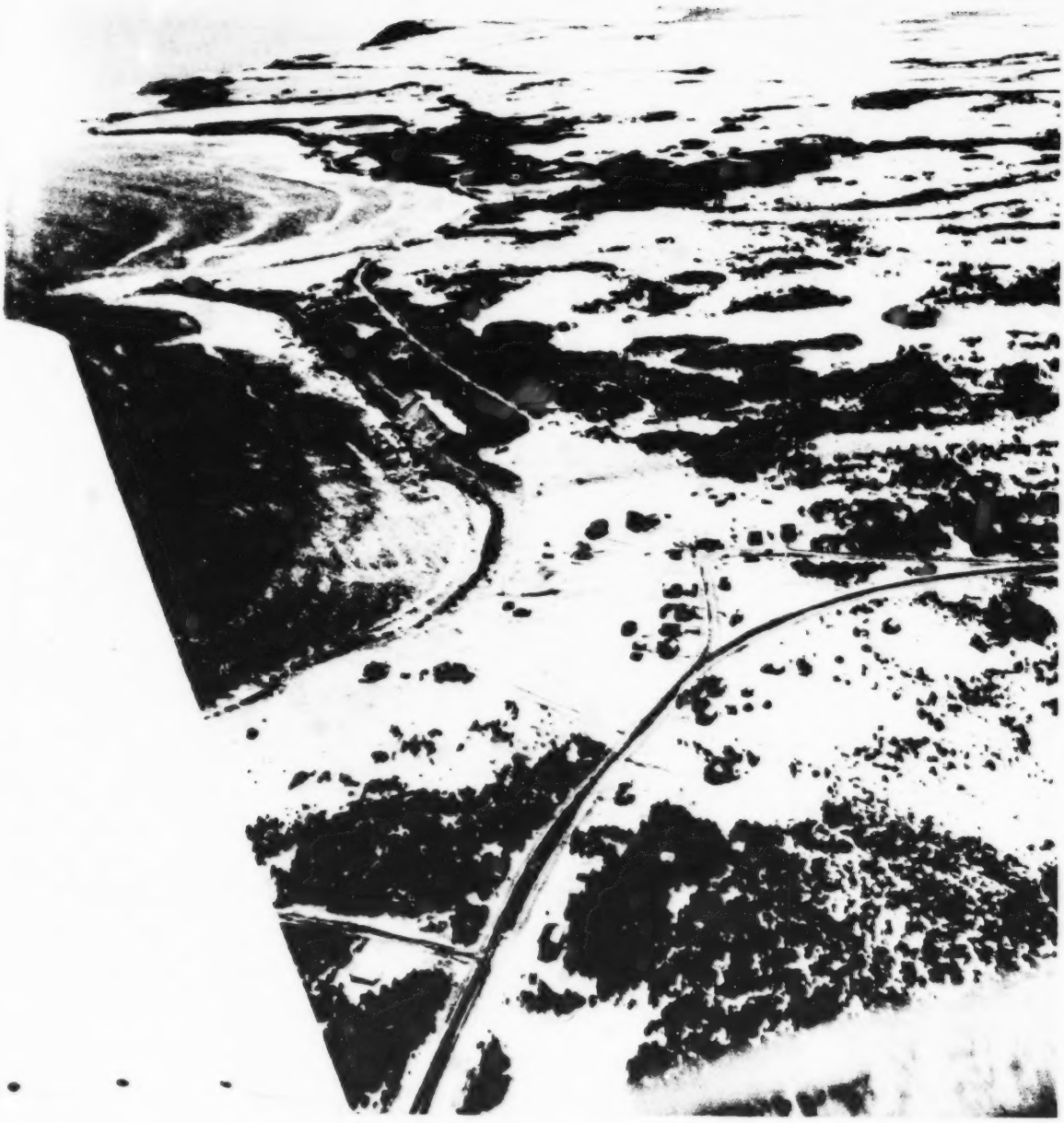


Figure 25: Aerial Photograph of Cappahayden Test Site

5.2 Cappahayden Field Trials

On February 18 the basic radar equipment minus the computer was set up for a first look at the time series of ocean radar backscatter. The test took place at Cappahayden on the east coast of Newfoundland's Avalon Peninsula. (Lat. 46° 51' 40" N, Long. 52° 56' 45" W).

The Cappahayden test site was chosen because the coast line is easily accessible from a main road. The site provides a clear view of the ocean area over the Ballard Bank, for which limited surface and deep current meter data are available. Significant logistic support came from two local families who allowed us to use their property. One was the owner of a tourist lodge which provided excellent accommodation for the group.

Preliminary results from the 18th's radar trials indicated that the site would be suitable to carry out the first complete one-site CODAR field trials.

The site was re-established on February 22nd and subsequent data collection was performed.

The aerial photo- Figure 25, shows the test site's geographical location. The cove in the foreground is Cappahayden. Ballard Bank is at the top left most corner of the ocean horizon.

Figure 26 shows an overall map of the area with radar boresight and land unobscured radar coverage shown in solid and dotted lines respectively.

The entire radar system was operated from the back of a 1 ton van shown in Figure 27. Overall the setup was satisfactory to both operator and equipment with the exceptional problem of

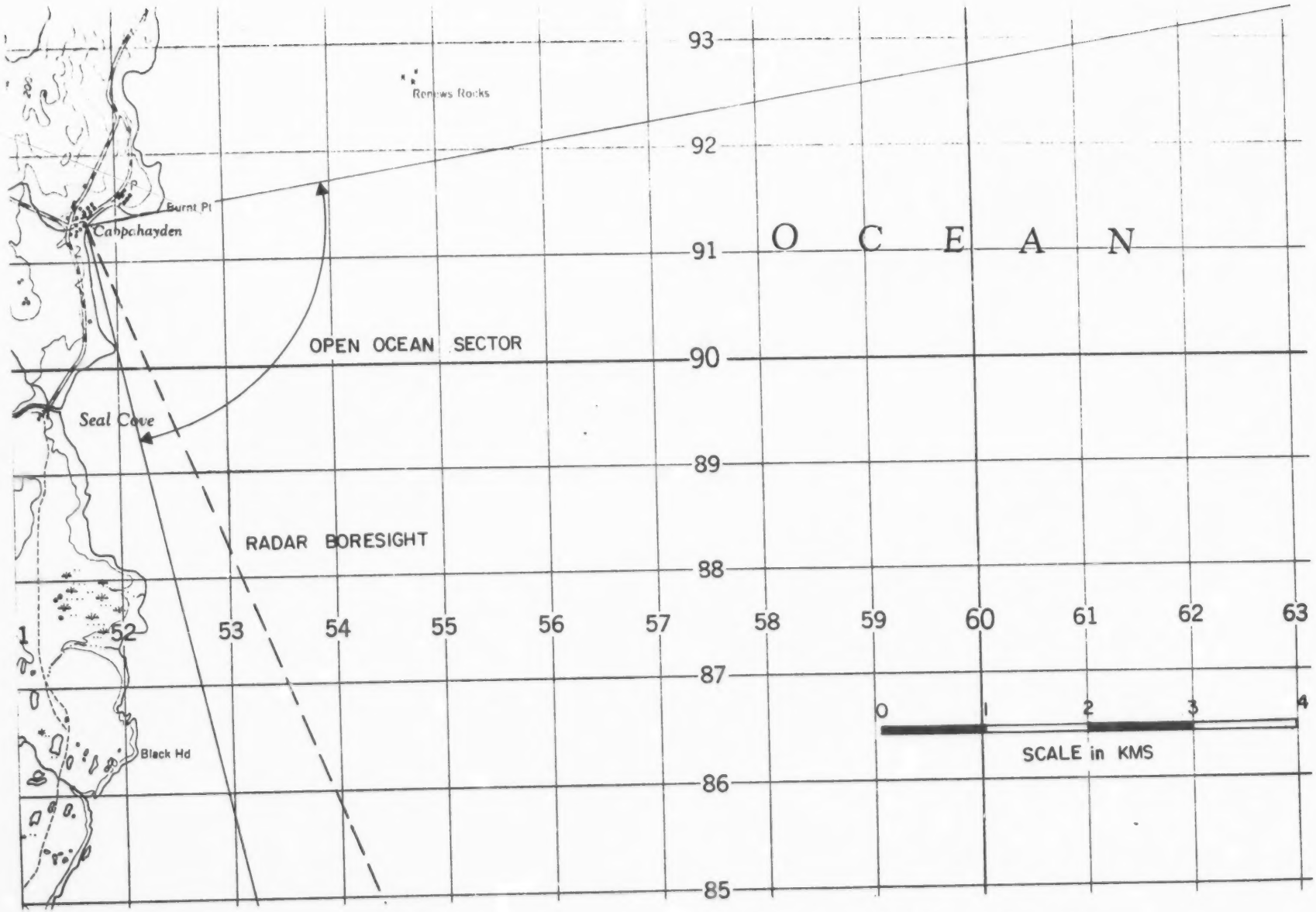


Figure 26: Geographical Map Showing Cappahayden Test Area

condensation of water on the steel roof. Styrofoam insulation of the roof in the future will not only eliminate condensation but also reduce heat loss.

Overall the equipment performed very well and no computer system "crashes" were encountered during the two day period. A total of 24, 18 minute 4096 point data sets were collected at 8 microsecond pulse width, including a 16 microsecond pulse width transponder run.

Figure 28 is a photograph taken of the VT100 CRT display during field operation, showing a 128 pt., 32 second power spectrum. This data was collected at range annulus 20 (ie: 24 km) on antenna #1. Note that the DC (centre) component has been removed to facilitate full screen normalization.

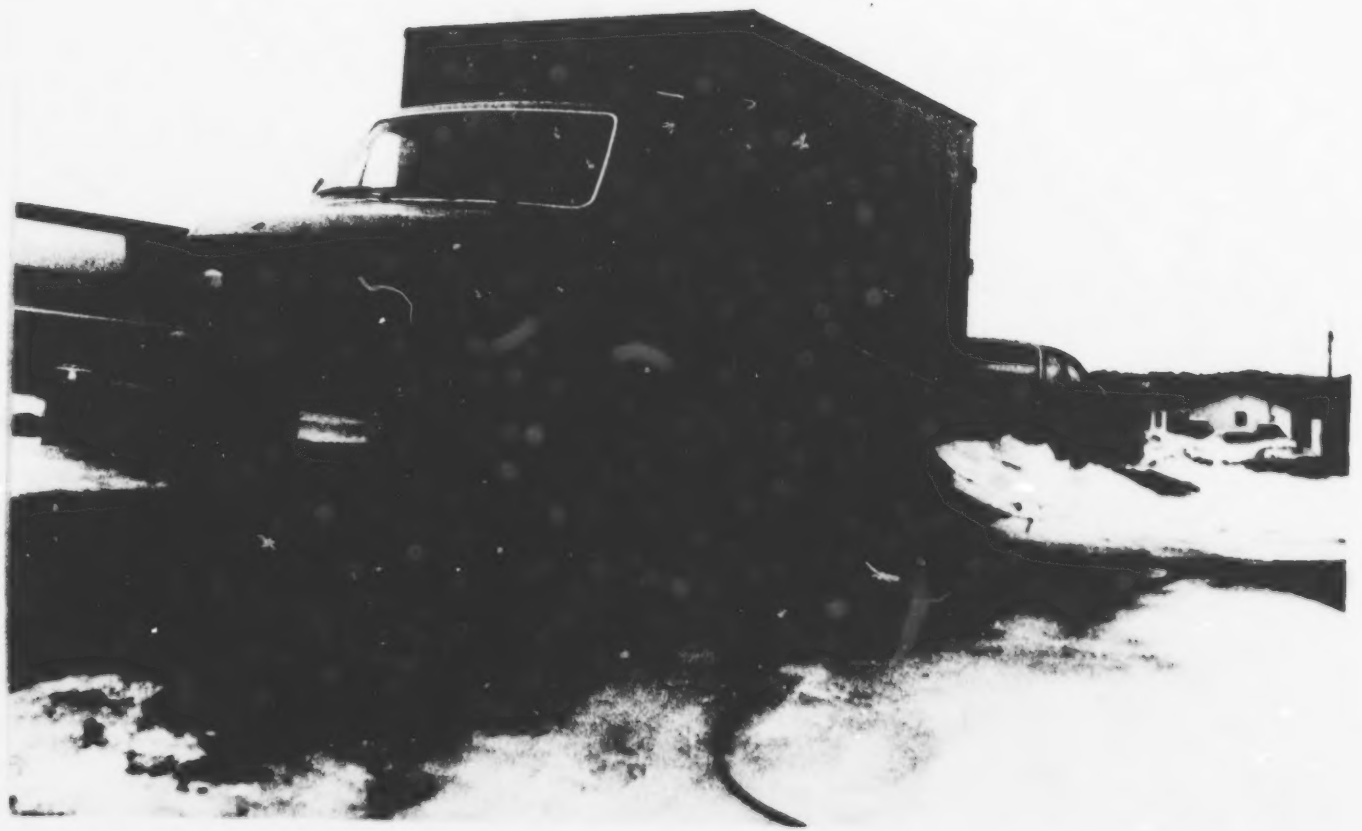


Figure 27: Photograph of Cappahayden Field Test Facility

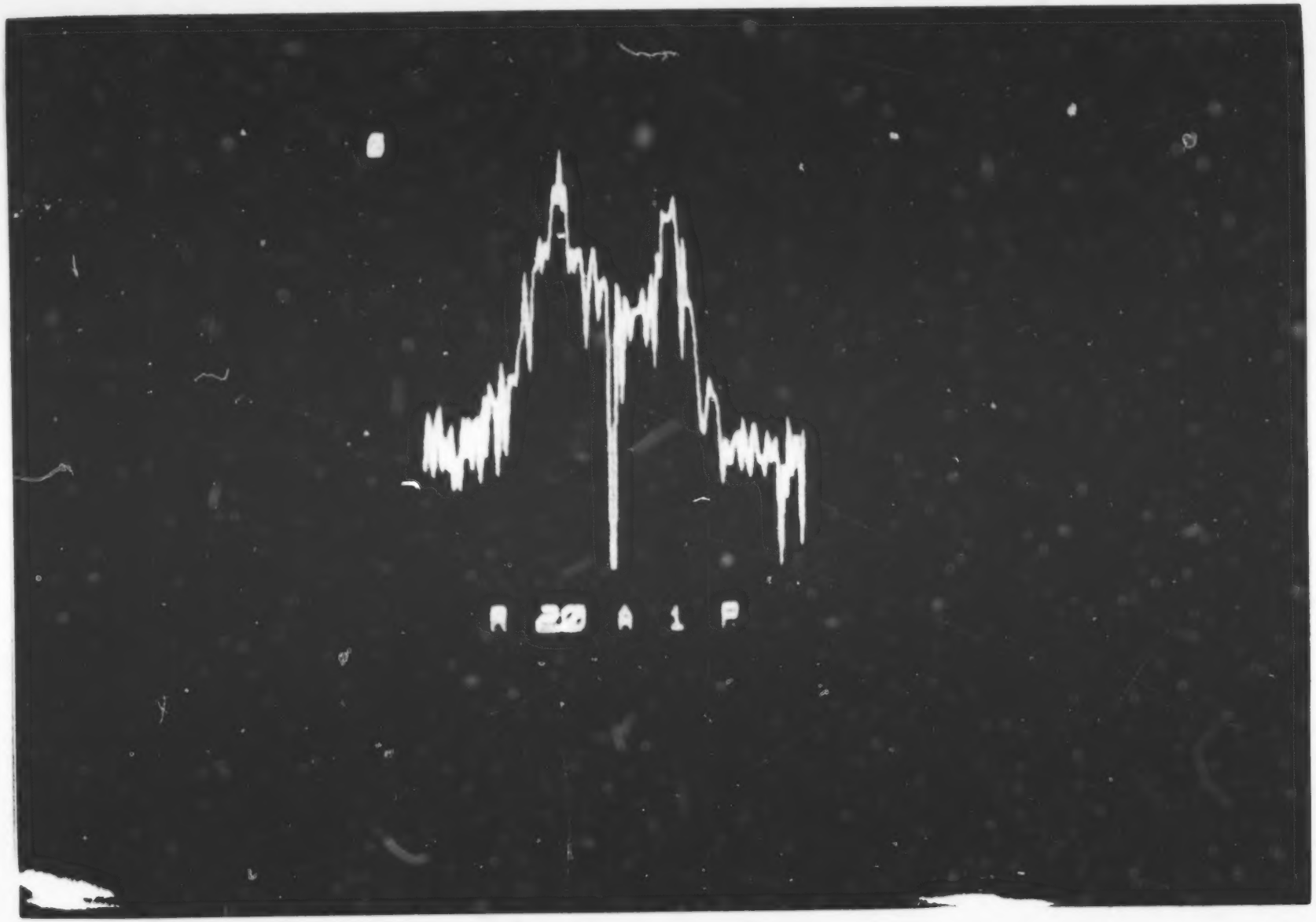
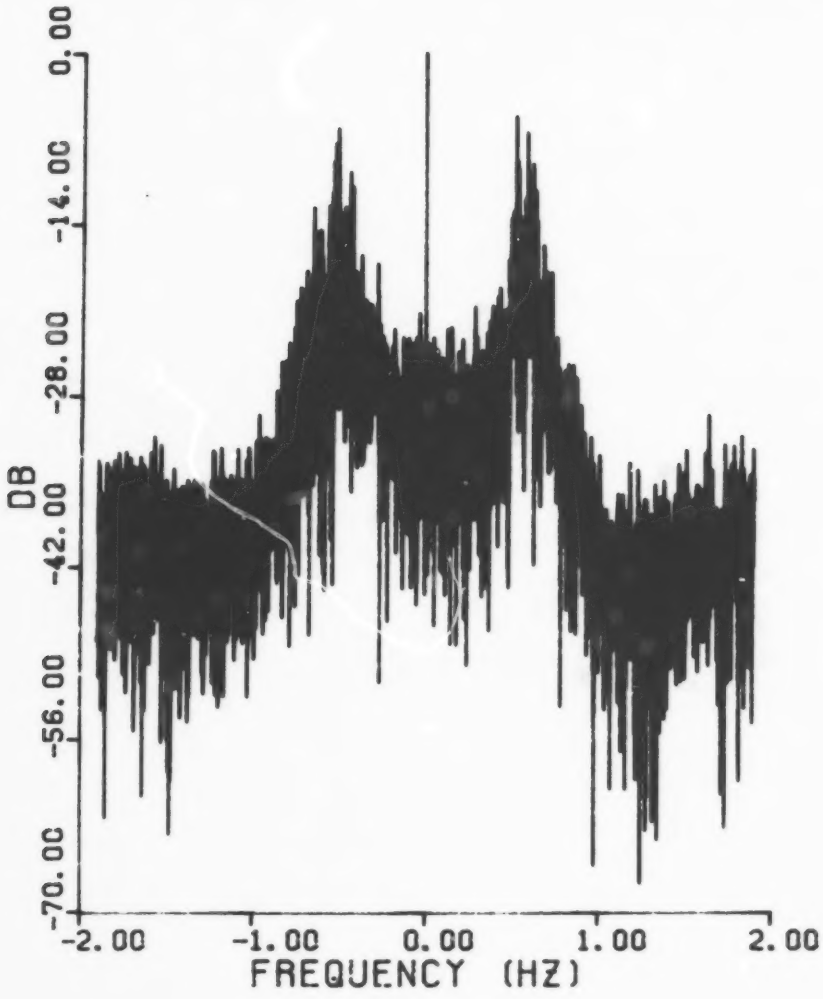


Figure 28: Photograph of Display CRT Showing Ocean Doppler Spectrum



Antenna: 1 Range Cell: 25
Run Time: 22-FEB-82 21:09 :
Latitude: 46 51 40
Longitude: -52 56 45
Antenna Boresight: 112.00
Frequency (MHz): 25.40
Pulse Width (us): 8.00
FFT Size (points): 2048

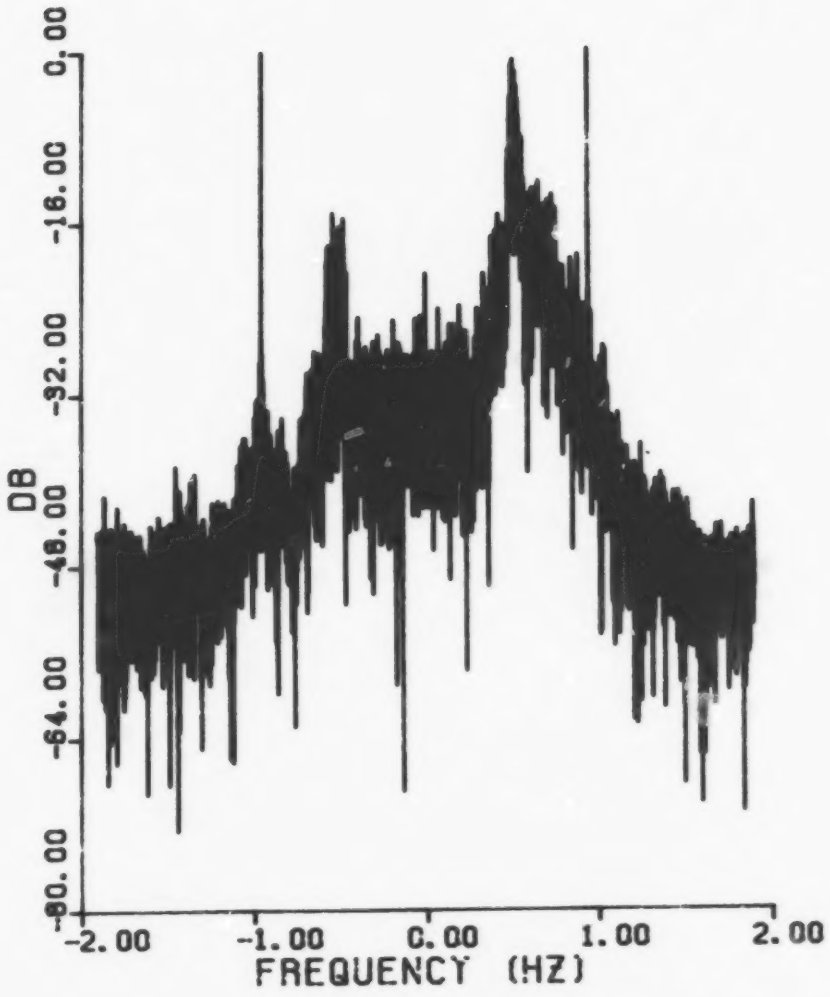
Figure 29: Ocean Doppler Spectrum Taken at 30 km Range from Cappahayden

6.0 PRELIMINARY DATA ANALYSIS

Preliminary analysis of the CODAR field trial data collected in February has begun but to date insufficient data has been analysed to permit discussion of detailed system performance in the current mapping function. Meanwhile several observations have been identified as worthy of note.

Figure 29 shows the result of a 2048 point, 18 minute spectrally processed time series taken from the Cappahayden test site at a range of 30 km. Based upon the experience of other users, the displayed ocean spectum indicates adequate quality to provide useful surface current data. Note that the first order spectrum is broader than one might initially expect. This can be explained by the fact that the antenna is omnidirectional and receives all current components simultaneously. Furthermore, the spectral purity of the processing technique is exemplified in Figure 30 by the clean, very narrow (one point at 30 dB) processed return of a stationary CODAR transponder. This also demonstrates the need to establish the compromise between extended processing time for increased accuracy, and increased Doppler history contamination.

The prevailing wind during the two day field operation blew generally from the north-east. In concert with the expected southerly direction of the Labrador current off Newfoundland's east coast, this would yield (during flood tide) a predominantly southward moving ocean surface. Initial results show a measured southerly direction of surface current flow as can be seen in the radial vector map of Figure 31.



Antenna: 1 Range Cell: 6
Run Time: 23-FEB-82 15:30 :
Latitude: 46 51 40
Longitude: -52 56 45
Antenna Boresight: 112.00
Frequency (MHz): 25.40
Pulse Width (us): 16.00
FFT Size (points): 2048

Figure 30: Ocean Doppler Spectrum Including Transponder Return

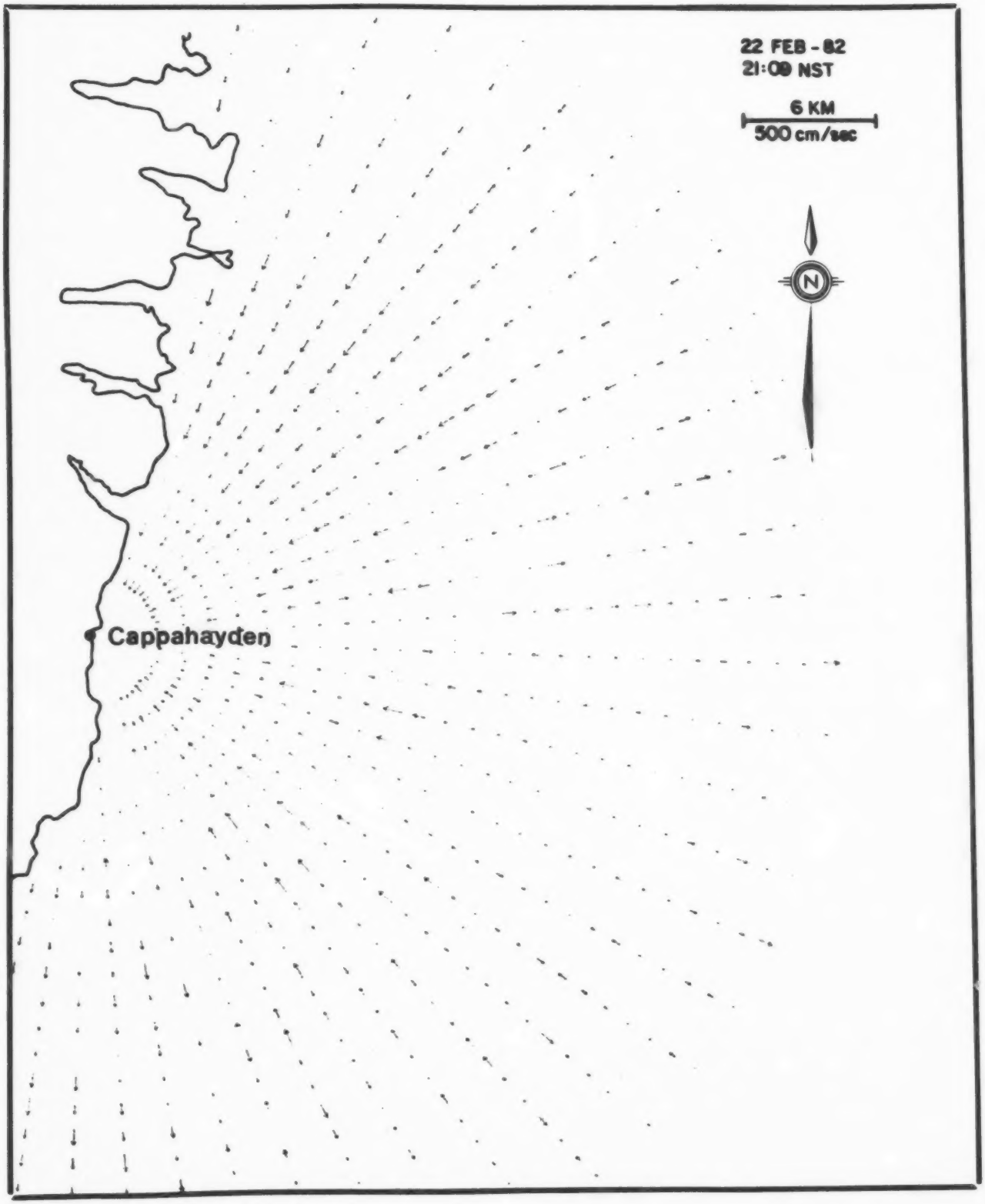


Figure 31: Radial Surface Current Vector Map of Cappahayden Area Produced from One, 9 minute, 2048 Point Complex Time Series

System errors are suspected as the cause of the projection of certain shear currents and large current variations on the map. Work is underway to establish the source of these instabilities. The continued efforts will concentrate on the data interpretation software. Well defined hardware tests such as controlled ramp levels to the receiver A/D converters have been performed and demonstrate that the data acquisition software works as intended.

Meanwhile, discussions with experienced CODAR data analysts at NOAA indicate that recent improvements have been made to their data interpretation process and are recommended for implementation in our system. Such improvements include detection and removal of time-series fliers (bad data) that are several orders of magnitude above the mean data amplitude. Also, multi-segment time-series detrending to remove long term drift should be considered. Low frequency contamination around zero Hz Doppler can adversely affect the dynamic range and hence the amplitude sensitivity of the interpretation process. Personal communication with Dr. Don Barrick of NOAA has revealed that operational experience with the closed form analytical solution to four element CODAR current mapping indicates errors that might be reduced through a statistical least squares analysis on the semi-independant antenna pairs from the same data. This should be researched further.

7.0 SYSTEM RECOMMENDATIONS

The following is a summarized list of recommendations that should be incorporated in both the hardware and software of each single site CODAR during the next phase of development.

HARDWARE

1. The gain curve for the CODAR transceiver should be linearized with respect to gain commands to enable implementation of stable automatic gain software control.
2. High temperature instabilities were encountered with the CODAR receiver 37.5 MHz crystal oscillator. This component will be replaced. A cooling fan should be installed.
3. The transponder control circuitry should be evaluated and modified to enable 8 microseconds pulse width operation.
4. The LSI 11/23 computer memory should be extended to full complement for implementation of improved data acquisition software as discussed in section 2.2.
5. Investigation of the potential of a cartridge type magnetic tape drive for application to data acquisition should be continued.
6. Special sealed aluminum environmental shock protected containers recently field proven in the Arctic should be adopted for all future packaging.
7. The receive antennas should be made rigid to prevent wind induced motion thereby reducing the risk of systematic Doppler contamination.

SOFTWARE

1. The plotting and system console should be integrated into one unit (VT100) using the Selanar graphics board. This involves modification of the console/display software.

2. An automatic gain algorithm with graphical console display should be implemented as discussed in section 3.3.

3. The data acquisition routine should be altered so that data is stored in a direct access disk file for time efficient data demultiplexing.

4. Gain constants should be logged on the data tapes (preferably at the end to be compatible with the existing format).

5. The real-time plotting routine should be modified to print the value of the removed DC component.

6. A routine should be implemented to monitor but not display the status bits of the CODAR transceiver during operation. (activate audiovisual alarm if trouble).

7. An antenna evaluation should be performed before each run and normalized values recorded for each antenna in the header. This would be a natural extension of an automatic gain algorithm proposed in 2.

8.0 PROGRAM FOR SECOND SITE DEVELOPMENT

The operational capability of CODAR is spatial mapping of ocean surface current vectors and repetitive mappping in a temporal sense. A short list of potential applications of this technology are: (i) routine environmental measurements to quantify coastal processes, (ii) the ability to monitor surface transport directly in the case of an oil spill accident, (iii) a potential tool to study ice and iceberg behaviour and (iv) remote surface drift measurement to support search and rescue.

An operational one-site CODAR Data Acquisition System has now been assembled at C-CORE. However, before the applications previously mentioned can be addressed, further development must take place.

The following program outlines in task format, the additional research and development effort necessary:

1. Preliminary analysis of one-site CODAR data indicates a vector assignment problem in C-CORE's interpretation process that is not related to the process task description (i.e.: possibly linked to data file structure reformatting). Certain process strategies such as quality factor assignment will also affect analysis results. It is therefore recommended that a minimum of four to a maximum of eight weeks be dedicated to evaluating these effects and carry out additional field work before proceeding with new software development. Our contacts with NOAA personnel can ensure progress.

2. A complete CODAR current mapping system requires two radar stations. Based on the results of C-CORE's one-site hardware

development program, the design configuration should be completed for a two site system. This task should only take a few days. A period of about six weeks may be needed to account for comprehensive supplier information feedback.

3. This program is developmental in some respects. As potential industrial user groups of CODAR are weary of supporting a high cost development program not under their direct supervision, it is recommended that the hardware for a second site be leased under an option to purchase. CODAR Technology Inc. of Boulder are developing single site hardare and are prepared to enter into such an agreement with C-CORE.

4. To permit real-time operation and efficient use of the computing hardware, certain computer interface hardware and extended memory are required. Due to anticipated hardware delivery dates, this procurement and implementation period would extend to the six month mark in the program.

5. A telemetry link is required between the two radar stations for efficient coordination of the data acquisition data for real-time operation. This and other between site data transfer systems engineering will continue through to the first tests of the two site hardware.

6. Practically 100% of the computer software necessary to operate a two-site system can be developed using one-site hardware. The following briefly lists the important tasks.

   a. Incorporate latest NOAA data analysis routines (ie. detrending and filtering).

b. Develop two site full vector graphics plotting including site digitization.

c. Transfer software to disk based real time data management.

d. Establish input/output routines to permit two site data transfer.

This portion of the program would be included in all ongoing interpretation software development and continue for a few months after the first two-site tests.

7. Sufficient field tests will be performed from a St. John's region site to assure complete two-site CODAR operational capability.

8. Eventually, permission to operate CODAR on a routine basis in a portion of the HF radio spectrum will be needed. The purpose of this task will be to ensure that as CODAR applications develop in Canada, all necessary steps will be taken to keep potential road blocks in this process to a minimum. Discussions with the Dept. of Communications have been favourable and NOAA recently started proceedings in the U.S. which will make our task easier.

9. Complete system documentaiation and a final hardware/software performance report will be produced.

10. C-CORE is presently planning for a major offshore Iceberg/Surface Current Detection and Monitoring Program for the late spring of 1983. It is expected that a complete two-site CODAR and narrow-beam HF receiving antenna array (supplied by C-CORE) will be available for the program. Program financial support has been indicated by Mobil Oil based on the production of

a comprehensive scientific plan. The primary purpose of this task will be the production of this plan.

11. Subcontractors will be utilized to fill in-house engineering gaps. Previous program management supplied by INSTRUMAR Limited will continue through the hardware development phase. Periodic consultation with CODAR Technology Inc. will continue.

9.0 SUMMARY

All of the main objectives of this phase of the program (1981/82) have been achieved.

A single site CODAR station has been assembled and operationally demonstrated in February, 1982 at Cappahayden on the east coast of Newfoundland's Avalon Peninsula. This of course included the implementation of CODAR data acquisition software as a prerequisite to successful operation. Hardware specifications are provided.

An Arctic field program was organized and executed at Pond Inlet, N.W.T. during March 1982. Data gathered will be used to evaluate an analytical model developed by Dr. J. Walsh to predict HF groundwave radio propagation over sea ice. Preliminary results are supplied in the appendix of this report.

Interpretation software to produce single-site radial current maps from CODAR data has been developed and fully implemented. There is however, need for further work on the interpretation process to clear up mapped radial component discrepancies encountered during preliminary reduction of both NOAA and C-CORE field data. Several areas where both data quality and analysis may be affected are discussed. Further field trials are planned and will address those specific concerns.

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APPENDIX

C-CORE ARCTIC HF PROPAGATION TESTS - MARCH 1982

FIELD TRIP REPORT

C-CORE ARCTIC HF PROPAGATION TESTS - MARCH 1982

FIELD TRIP REPORT

OBJECTIVES:
- To collect data on HF propagation over uniform first year sea ice (25.4 MHz).
- Compare results with theoretical model developed by Dr. J. Walsh (1982), A General Theory of the Interaction of Electromagnetic Waves with Isotropic Horizontally Layered Media and Applications to Propagation over Sea Ice, C-CORE Technical Report 82-9. This work also agrees with the results of J.R. Wait (1962), Electromagnetic Waves in Stratified Media, Oxford, England, therefore Pergamon Press, Chapter 2. For the particular case of an infinitesimal dipole in free space resting on a flat medium, the vertical component of the electric field (Ez) at the surface a distance R away is given by;

$$Ez = 2EoF_{(w)} \ (1 - \Delta^2) \ \frac{e^{-jkR}}{R}$$

where

F(w) is the Norton Attenuation function,

Δ is the normalized complex surface impedance of the medium,

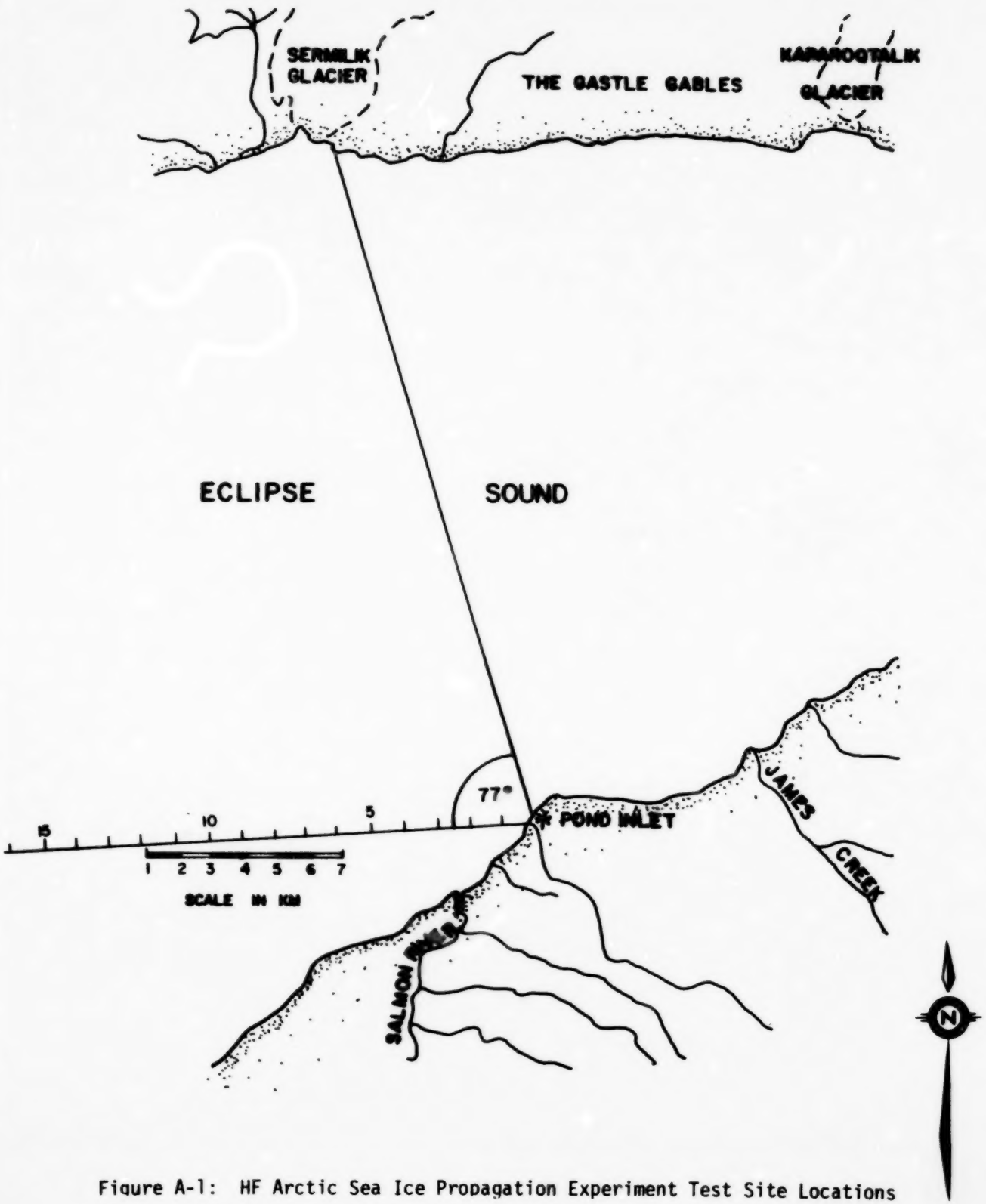

Figure A-1: HF Arctic Sea Ice Propagation Experiment Test Site Locations

$\frac{e^{-jkR}}{R}$ is the free space Green's function,

Eo is an antenna constant

EXPERIMENTAL REQUIREMENTS: For a successful experiment the following requirements should be established:

- large area of uniform first year sea ice
- well defined propagation path
- measurement of propagation loss as a function of distance (at 25.4 MHz)
- measurement of phase velocity as a function of distance (at 25.4 MHz)
- sufficient information to characterize the ice as a layered dielectric medium in the region of propagation
- phase locked HF transponder
- stable coherent HF receiver and transmitter

SITE LOCATION: By previous arrangement Arctic Research Establishment surveyed first year ice for uniformity in the vicinity of Pond Inlet. Based on their findings a straight line was then marked off at intervals of approximately 1 km, over the area of ice considered most uniform (Figure A-1). Arctic Research Establishment was also contracted to install two thermocouple chains in the ice on the line of interest, at the midpoint and end of the line.

Measurements taken by a C-CORE ice engineering team, already in Pond Inlet prior to our arrival, indicated the ice thickness

was most uniform between km 1 and km 16 on the designated line.

This line became the well defined propagation path over which measurements were made.

EQUIPMENT: Details of the transponder, transmitter, and receiver are given by Butt et al., (1983), HF Radar Technology Transfer Project - Acquisition Phase. March 82, C-CORE Technical Report 83-8.

The equipment used is part of the same equipment also used for Codar current mapping with the exception of the "range/gain" control box used to substitute the LSI 11/23 computer for receiver operation.

OPERATIONAL CONSIDERATIONS: The transponder's basic function consists of receiving a broadcasted 16 Usec pulse at 25.4 MHz, and then retransmitting the pulse with a 25 Usec delay.

The cycle of operation is:

i) transmitter transmits @ 10 kW peak

ii) pulse reaches transponder

iii) 25 Usec later transponder transmits @ 2W peak

iv) pulse reaches receive antenna and is de-coded by receiver into "in phase" (I) and "quadrature" (Q) components.

The expression $(I^2 + Q^2)^{1/2}$ is the magnitude of the returning transponder pulse at the output of the receiver which includes system gains. The ratio of Q to I can be related to the phase of returning transponder pulse.

THE EXPERIMENT

The C-CORE research team arrived in Pond Inlet the night of March 8, 1982. The required equipment (pre-shipped and waiting in Pond Inlet) had arrived apparently undamaged.

March 9th and 10th were consumed with equipment assembly, overcoming logistic support problems, operational testing of the equipment and dealing with an unexpectedly high noise background. The noise background was so large that the receiver was saturated at low gains, preventing the identification of the transponder signal (buried in the noise floor).

This large noise floor was observed while testing the equipment in a heated hut located on the coast at the beginning of the line of interest, where the equipment was stored for protection and warmth nightly.

The term "noise floor" is used because the source of the interference could not be determined. However, the interference may have been caused by the close proximity and quantity of transmit antenna cable near the receiver. (i.e. space restrictions prevented full layout of all cables).

The equipment was then moved to a moderately heated tent at km 1 of the line (see Figure A-1) sitting at the edge of uniform ice along the line (ref: "site location"). The noise floor there was much lower, allowing higher receiver gains to be used, permitting an operational check of the transponder (using the receiver).

By the end of March 10th a number of goals had been accomplished. The transponder, transmitter, and receiver were

confirmed to be operating properly from power provided by 1.5 km gasoline "flywheel" type generator. Transmit and receive antennas and cables were now permanently located around the tent in preparation for propagation measurements. In particular a location of minimum noise background had been located for the receive antenna within the radius of its 200 ft cable. All available methods for further reducing possible sources of noise interference, such as grounding equipment to sea water beneath the ice, screening and grounding electrical generators, re-locating generators etc. had been examined and noted. Most logistic problems were resolved.

During March 11th, 12th and 13th all electrical measurements were completed.

The methods for both near and far field measurements were basically the same;

i) the transponder would be located a known distance along the line from the receive antenna. The receive antenna remained in a fixed location near the tent.

ii) the transponder antenna would then be moved (a few metres at most) to obtain a maxima of either the "I" (in phase) or "Q" (quadrature) receiver outputs (either situation was equally acceptable, resulting in I (maximum) Q (minimum) or vice versa). Photos were then taken of the I and Q outputs displayed on a 465B oscilliscope showing the maxima/minima condition; with all pertinent data being written down such a receiver gain, distance etc.

iii) a 30 metre tape was then laid out from the position of the transponder antenna (0 metres) along the line in the direction of the receive antenna. The transponder antenna was then slowly moved to the 30 m mark. While the antenna was being moved the 'scope' was monitored to count the number of subsequent maxima/minima conditions (as observed at 0 metres) each of which represented a half wavelength displacement of the transponder antenna. The transponder antenna was then moved in either direction to locate the 5th maxima/minima condition. The net distance moved was then recorded. In addition the I, Q, and trigger information were simultaneously being recorded on tape using a Racal Store 4-D instrumentation tape recorder.

Exceptions to this procedure occurred when the transponder signal could not be observed above the noise floor. Under those conditions only part i) was performed with the I, Q, and trigger information recorded on tape (for future analysis), and all pertinent data written down.

During the near field measurements the transponder antenna was only moved through one half wavelength (not five) in order to avoid averaging the wavelength over distances comparable with the range.

The data from part ii) would yield transponder magnitude for a given range. Part iii) would yield the average wavelength at the transponder site from which local phase velocity can be calculated.

A list of transponder sites is included on page 105.

Ice cores were taken to within 10 - 15 cm of the sea water by the C-CORE ice engineering group in a number of locations on the line (of interest). Arctic Research Establishment was contracted for two additional cores, including analysis. A list of all coring sites is included on page 106.

Salinity analysis of the cores taken by the C-CORE ice engineering group was performed by C-CORE personnel at Pond Inlet. Two hundred 50 ml samples of those same cores were brought back to St. John's for additional analysis and cross correlation.

Temperature information from all thermocouples was recorded. A list of thermocouple sites is included on page 107.

Ice thickness measurements were also made along the line of interest by the C-CORE ice engineering group.

The salinity temperature, and thickness measurements will be used to characterize the ice as a layered dielectric medium.

By March 14th it was felt we had obtained all the information we could, within our time frame. to attain our objectives. The day was spent packing up equipment in preparation for our return.

Both C-CORE teams left Pond Inlet mid-day March 15.

CONCLUSIONS

1) The experiment was very successful in obtaining information. The C-CORE team left Pond Inlet with the feeling that they had sufficient data to characterize HF propagation over uniform first year ice.

2) The equipment performed extremely well down to 0°C and was rugged enough to withstand mechanical shock twice a day while riding the komatiks to and from the storage hut. However, the special container used to house the equipment deserves some of the credit.

3) The ability of the noise floor to hide the transponder pulse identifies an application for on site computer processing to maximize range.

4) A new material for the exterior of the antenna cables that would be less rigid at -40°C would be an improvement.

5) The taping over of connectors at adapter joints should be avoided since it prevents visual identification of unscrewed connections. This occurred once at an elbow connection but was caught before measurements were taken.

6) The power l.e.d. on the transponder indicates power even when there is not enough voltage for proper operation. This should be changed. We lost a good part of the day because of this.

PERSONNEL

Mr. Ernie Reimer - Field Management
Ice Engineering Group

Mr. Ken Klein - Principal Investigator
Ice Radar Group

Mr. Terry Ridings - Field Technologist
Ice Radar Group

Ms. Deborah Diemand - Core Analysis
Ice Engineering Group

TRANSPONDER SITES

Near Field Measurements:

range to receiver antenna
210.6 m
180.0 m
150.5 m
120.4 m
89.6 m
59.7 m

NOTE: Parts i), ii), iii) of the experimental procedure (ref. the experiment) were completed at each site

Far field measurements:

range to receiver antenna	*experimental procedure completed* (ref: the experiment)
0.67 km	parts i, ii, iii
1.35 km	parts i, ii, iii
1.90 km	parts i, ii, iii
2.45 km	parts i, ii, iii
3.00 km	parts i, ii, iii
3.54 km	parts i, ii, iii
5.73 km*	part i
6.88 km*	part i
7.91 km*	part i

* (transponder signal buried in noise floor)

ICE CORING SITES

C-CORE ICE ENGINEERING GROUP

range to receiver antenna	no. of cores	date
0 km (area of tent)	9(taken over a square area 60m X 60m)	
		March 2, 3
0.67 km	2	March 12
1.35 km	2	March 12
	1	March 6
1.45 km	1	March 6
1.55 km	1	March 6
1.65 km	1	March 6
1.75 km	1	March 6
1.90 km	2	March 12
2.00 km	1	March 6
2.45 km	2	March 12
	1	March 6
3.00 km	2	March 12
	1	March 6
1 km (off line of interest located 1 km from Pond Inlet along line joining Pond Inlet and Sermilik Glacier)	1	March 9
6.88 km	1	March 10
15.33 km	1	March 10

NOTE: All cores except those noted were taken on the line of interest.

THERMOCOUPLE SITES

range to receiver antenna	installed by
1 km (off line of interest located 1 km from Pond Inlet along line jointing Pond Inlet and Sermilik Glacier)	Arctic Research Establishment
6.88 km	Arctic Research Establishment
15.33 km	Arctic Research Establishment
0 km	C-CORE ice engineering group

NOTE: All thermocouples except those noted were located on the line of interest.

POOR

QUALITY

ORIGINAL